GROWING CYBERNETIC EARS:

TRANSDUCTION AND PERFORMATIVITY IN THE ANALOGUE AND DIGITAL WHAT HAVE YOU

Joe Watson

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ABSTRACT

At a time when digital technologies have become ubiquitous in music making, and where the majority of research into music technology happens at the computational 'cutting edge', this practice-based PhD explores analogue technologies deemed, in the main, obsolete, anachronistic, or as quaint nostalgic throwbacks, and asks how a combination of technological, historical and practice-based research, focused through commitment to artistic outputs in the domain of music technology, might shed new light on the terms analogue and digital, and on the nature of the analogue-digital relationship.

Underlying much contemporary enthusiasm for 'the digital' are progress narratives that rely on both a succession logic (old analogue technology gets replaced by new digital technology) and an assumption of isomorphism (the digital technology does all the same things as the replaced technology, though often with 'enhanced' affordances). This thesis questions such assumptions along historical, philosophical and practice-based trajectories.

Key to these research trajectories is the trans-discipline cybernetics, in particular the second-order cybernetics of Gordon Pask, whose self-designation 'philosophical mechanic' indicates the importance he placed on a cyclical, mutually accommodating thinking-designing-making. Pask presented a powerful practical methodology for the examination and creation of dynamical systems in flux, systems that evolve as a result of participant interaction, systems that can be seen to manifest self-organisation. Second-order cybernetics puts the emphasis on processes in interaction rather than positing pre-existing objects (including concepts) in a world 'out there'. Cybernetics helps us to explore systems whose complexity and interdependence precludes the separation out into constituent parts, systems where control is shared across multiple mutually interacting dimensions, and where the observer is a committed participant whose actions, interests and biases cannot be divorced from the interactions therein.

Two other key concepts are: (1) transduction, which relates energy, information, patterns of growth, or other dynamical processes across media or between domains; (2) performativity, an interventional act that brings forth a world. Transduction is essential to an understanding of recording studio processes and practices: the microphone, signal processing and recording itself all rely on transduction. When viewed from a performative perspective, actions such as recording are found to be carried out very differently when the final stage of transduction is discrete (the case with the now ubiquitous digital audio workstation) or continuous (such as recording to tape). This difference is primarily due to the hyper-plasticity of digital audio, a taking of sound 'out of time'. Rather than seeing this as an evolution of 'precursor' analogue technologies, as most accounts have it, this thesis takes the perspective that this is a difference in kind, rather than one of degree, and explores that difference with a particular focus on emergent and intertwined cultural, embodied and technological systems, rather than on end products.

The second half of the thesis presents the compositional practice, ranging from experimental work on tape music composition and installation, through a series of modular synthesis live performances, to tape-based recording of pop music. The physical, gestural engagement with the resistant materiality of these technologies emphasises a very different cognitive engagement with processes of composition and production to that which happens with supposed 'successor' digital technologies; assumptions of isomorphism, buttressed by skeuomorphic emulation, tend to occlude this cognitive distinction.

This thesis is offered as an act of cybernetic musicking – resolutely practical in orientation, with a wide-ranging, trans-disciplinary theoretical framework, and with the emphasis not on things but on ongoing processes in complex interaction with a world in constant becoming.

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Dedicated, with love, to Roger

STATEMENT

This thesis, and the accompanying portfolio of musical compositions, has not been previously submitted to this, or any other University.

INCORPORATION OF PUBLISHED WORK

Elements of chapter 5 have been published as part of the proceedings from the International Conference on Live Interfaces (ICLI) 2018 (https://live-interfaces.github.io/2018/pdf/ICLI2018-Watson.pdf)

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THESIS MOTTO

"It's growing an ear", Gordon Pask (quoted in Beer, 2001, 555).

INTRODUCTION

The analogue-digital distinction matters. It is a "difference which makes a difference" (Bateson, 2000, 315).[1] Distinction does not mean opposition: analogue does not equal 'not digital'. Rather, the analogue-digital distinction denotes a systemic demarcation that has, in some 80 or so years of *conjoined* significance, allowed scientists, engineers, philosophers, musicians and others to gain some purchase on various processes, primarily technological, but also biological and cognitive. Like an analogy, in that it "always involves both a similarity and a distinction" (Pask, 1979a, 221), but generatively the inverse, the analogue-digital relationship is one of cleaving apart across an axis of similarity: analogue or digital computation, recording, signal, watch, or what have you.[2]

It is certainly not the only way to make a cut in the domain of technological musicking[3] – this thesis also offers transduction and performativity as fruitful alternatives – but, given the contemporary privileging of the term 'digital', academic attention given to 'the digital', and the well-known ubiquity of digital devices in music technology (as in a bewildering profusion of other areas), the analogue-digital distinction is examined here in some considerable detail. This exploration, both practical and theoretical, is offered: (1) in reaction against the strange state of affairs where analogue has come to mean 'not digital', or 'everything outside of the computer' (see Sterne (2016), and cf. chapter 2); (2) in support of some much needed contextual and technological specificity such that the two terms can continue to do useful work in a variety of areas; and (3) as antidote to what seem to be prevalent tendencies in contemporary culture: a fixation on the computational, with underlying assumptions that digitisation is

[1] Bateson is discussing "units of information", rather than the analogue-digital distinction. I employ this quote because of its productive resonances, and because the demarcation of meaningful distinction, which Bateson is referring to, is central to what follows.
[2] Generation of analogy is, inversely, creation of a similarity across an axis of distinction.
[3] See Small (1998) and cf. p.7.

inexorable, that a digital 'switchover' is inevitable, and that 'analogue' is by nature obsolete, or at best, anachronistic.[4]

The analogue and digital 'what have you', of the thesis title originates in a footnoted comment by John Haugeland, discussed in more detail in chapter 2 (cf. p.34). It baulks a persistent contemporary tendency to pronounce on 'the digital' (and to a lesser extent 'the analogue'), by insisting on the need for contextual specificity when using these terms. This thesis proposes that any useful definition of either term is impossible unless the term prefixes a referent, a noun, a process, or what have you. Thus one can define analogue or digital computation, but the definition will not port over to analogue or digital recording. The analogue and digital what have you thus operates as a placeholder for all the things analogue and digital *may* prefix, while insisting that they cannot exist in isolation and *must* prefix something.

In both scholarly and commercial accounts of music technology history, one of the most common stories told about how we got to where we are is of *replacement along lines of continuity*. In this narrative an analogue technology is replaced by a digital version that does all the same things, in a similar way. For example, multitrack tape is supplanted by the digital audio workstation (DAW). The digital version is frequently presented as offering enhanced affordances, such as the 'greatly improved editing facility' of the DAW, or the way a digital synthesis environment can offer everything a (physical) modular synth does, plus the possibility of hundreds of oscillators (impracticable in a physical system where each oscillator has a significant cost). In this narrative of replacement there is an underlying and frequently hidden *assumption of isomorphism*. Once the principles of (for example) analogue synthesis have been 'understood' (formalised, represented in mathematical form) then they can be instantiated in a digital system, and then presented as providing exactly the same functionality as the 'equivalent' analogue system. There are at least two problems with this commonly held assumption: (1) A formal representation of a real-world physical process is *not* the same as the

[4] A note on use of quotation marks in this thesis: double quotation marks are used for direct quotations from a listed author. Single quotation marks are used to 'scare-quote' and to indicate 'what people say'.

physical process – it is a simulation, emulation, mathematic model, or some other quantifiable abstraction (Pattee, 1995). (2) This perspective tends to elide the user of the technology; it concentrates on 'end results' (multitrack audio, the behaviour of a synthesis system, parity of sounding behaviour between a piece of signal processing hardware and a software emulation) and does not pay attention to how differences of modality, gesture and ergonomics affect not just how that technology is actually used in practice, but also the essential underlying cognitive processes involved in engagement with that technology. In other words, it ignores the body. Theories of embodiment, such as Varela et al.'s "enactive cognition" (Varela et al., 1993), as well as ideas of tacit knowledge (embodied know-how) in Gordon Pask's cybernetics (Pask, 1975a) and elsewhere, are important to what follows.

In order to investigate the significance of physical, embodied engagement with technologies, this thesis takes a *practice-based* stance (which we could also call a Paskian cybernetic stance, cf. p.16) to the underpinning research, and takes very seriously the differences that make differences that arise when considering how the physical body engages with technologies of music making. Interrogation of the assumption of isomorphism that underpins various *progress narratives* proceeds by directly engaging with technologies that are deemed, in the main, to be obsolete, supplanted and improved upon by digital 'successors'. This engagement operates across three areas of music technology: (1) *Musique concrète* and a practice of *tape-music composition* are generally assumed to have been replaced by sampling technology and by the affordances of digital audio. In order to investigate this I set up a tape music studio and explored classic *musique concrète* techniques.[5] I also created two sound installations that allowed audiences to explore the materiality of tape.[6] (2) *Modular synthesis* presents a slightly different case, as this area is generally not considered obsolete, and there is a healthy worldwide modular synthesis community. Computer synthesis systems do not necessarily succeed analogue forebears, since developments occurred in parallel, but the same principles of isomorphism are still often assumed: a filter is a filter, regardless of

[5] Documentation at http://euterprise.com/index.php/music-research/musique-concrete/
[6] Documentation at http://euterprise.com/index.php/music-research/sound-installations/

analogue or digital instantiation. My modular synthesis work is documented at http://euterprise.com/index.php/music-research/modular-synthesis/ and discussed in chapter 5, which focuses primarily on a modular synthesis performance piece called *The Thing Breathed*, which was performed several times between 2015 and 2018. (3) The obsolescence of the *multitrack tape studio* has been loudly trumpeted (cf. p.116), and contemporary *pop music production* is absolutely dominated by the DAW; although tape-based alternatives are not difficult to find, the ubiquity of the DAW and assumptions of technological progression still abound here. To explore this I employed the very tight constraints of 8-track multitrack tape as a basis for the recording of four pop songs: the Euterprise EP (documented at http://euterprise.com/index.php/music-research/euterprise-ep/ and discussed in chapters 3 and 6).

In all cases, my own history of technological musicking meant that I came to these 'predecessor' technologies from a position of 'digital literacy': I had spent many years working with samplers and sequencers; I had practical knowledge of digital synthesis systems such as Max/MSP, used in the making of sound installations and other outputs; I had spent years as a professional sound engineer working with various DAWs in all kinds of studio setup and environment. In all cases, and as a result of practice-based exploration, I find the assumption of isomorphism to be misplaced. This insight can only come from a practical engagement with the actual technology: simulations or surveys of available literature do not engender the same conclusions. This is discussed throughout the thesis.

But practical experiments and investigations may mean little in and of themselves. The PhD is, after all, an attempt to generate new insights, or 'original contributions to knowledge', within a certain domain or discipline. Thus, this thesis builds a theoretical framework that puts this questioning of commonplace assumptions and ubiquitous technologies into a wider scholarly framework. The most important part of this framework is that elucidated by second-order cybernetics, in particular the thinking and practical investigations of Gordon Pask. This cybernetic perspective is introduced in chapter 1 and then explored in detail in chapter 3, which attempts to build a Paskian 'cybernetics of the recording studio'. Chapter 1 also delineates a methodology and introduces the key

theoretical concepts *transduction* and *performativity*. Chapter 2 explores the analogue-digital distinction at some length, both from a historical and technical perspective, and arrives at the somewhat provocative conclusion that *analogue and digital always and only coexist*. In addition to highlighting the need for a conjoined specification, I argue that there is no single overriding definition of either term, or their relationship, that will hold true in every case: to call something analogue or digital is always to take a perspective, to make an interpretation, to demarcate a distinction: activities about which cybernetics has important things to say. That there is no single reliably absolute way to define analogue and digital has far reaching ramifications given the contemporary prevalence of not just digital technologies, but also the term 'the digital'.

After these three contextual, theoretical chapters, come three chapters examining and evaluating the practical research. These chapters are supported by the documentation at http://euterprise.com/index.php/music-research/. Chapter 4 looks at experiments in tape music composition and installation. This is where I started to seriously question assumptions of isomorphism, as my sampler-literate thinking assumed all kinds of things to be possible which, in practice, turned out to be otherwise. Chapter 5 examines modular synthesis in live performance, primarily investigating a single piece *The Thing Breathed*, which uses multiple nested feedback networks instantiated in analogue electronics. Performative engagement with the system reveals a complexity that resists rational penetration, reliable pre-programming and the like, and yet remains a compelling conversational partner. The continuous analogue electronics underlying both system and interface manifest *concurrency*, a property not generally available in digital systems. Chapter 6 looks at tape-studio based production of pop music, and finds performance, gesture and commitment to be fundamental to all activities therein; by comparison, the DAW is found to be somewhat lacking in these regards. Appendix 1, a technical glossary, is offered as support to those readers without extensive knowledge of the jargon of music technology. Appendix 2 gives further detail on the documentation. Appendix 3 discusses the Euterprise EP vinyl record, included with the PhD submission.

Although the focus of the practice described here addresses specifically musical concerns, this research may also be of interest to practitioners and theorists concerned with: (1) the ubiquity of the digital what have you in our current cultural moment; (2) the dominance of the computationalist framework in AI, cognitive science, and increasing swathes of contemporary culture; (3) embodiment, gesture, performativity, interaction in a variety of technological and cultural domains.

This thesis taps into the recent resurgence of interest in cybernetics, applied here specifically to usage of technology in contemporary music research and practice, but also more generally. The thinking and making of Gordon Pask is particularly apposite here, and his cybernetic methodology is adopted and adapted to my own musical and theoretical needs. This thesis may thus also be of use to those interested in the ongoing rekindling of interest in cybernetics, particularly second-order cybernetics.

This thesis also draws from a historical trajectory of questioning, scepticism or concern with overly computational approaches, running from the Macy conferences in cybernetics (1946 to 1953), through dissenting voices such as Dreyfus, Winograd and Flores, Penrose, taking in respectful but contrary approaches such as those of Pask and Pattee, and more contemporary views such as those of Cariani and Pickering.[7]

And as I rewrite this introduction for the umpteenth time, this time, I hope, at the end of the process of the PhD, I review what is to come and note one further concept that I have found increasingly important, and to which I have not given adequate acknowledgement: that of *musicking*. Christopher Small's coinage insists on music as *process* rather than thing, verb rather than noun; it highlights action, flux, passage, and the complex interweaving of active, engaged agents. It thus contributes to a rich philosophical trajectory that foregrounds process, activity, performativity and becoming. It is outside of the scope of this thesis to trace

[7] Both Boden (2008) and Varela et al. (1993) offer comprehensive surveys of this historical trajectory, from very different orientations.

historical roots of this trajectory; I note, in passing, certain contributions to this current, each of which is important to what follows: Simondon (2016), individuation; Barad (2007), "intra-action"; Buckminster Fuller (1970), "I seem to be a verb"; Maturana and Varela (1992) "languaging"; Varela et al. (1993) "codependent arising"; and Pask (1979a, 216), for whom "units of reality *are* processes".

Other literature germane to the theoretical scaffolding of this thesis includes: Andrew Pickering's recent work on British cybernetics (Pickering, 2011, 2009), which confirmed cybernetics as a potent avenue of exploration for this research. Attempts in the thesis to understand and define the analogue-digital distinction lean on scholarly debate from the beginning, middle and end of its 80 or so year conjoined history: the early years are explored in a detailed discussion from 1950's 5th Macy Conference in Cybernetics (Gerard, 2016). Here we see that the basic tenor of the distinction is very similar to later technical and philosophical treatments, but that agreement as to exact definition was ultimately insoluble. The middle period of the debate explores John Haugeland's philosophically oriented article 'Analog and analog' (1981). Here we learn that the terms are 'substantive-hungry' – they need to take a referent in order to be meaningful. Recent scholarship into this area centres on a discussion by Jonathan Sterne (2016), who explores the curious state of affairs whereby in popular culture 'analogue' comes to mean 'everything outside of the computer'. This thesis disagrees with some of Sterne's assessment of the nature of analogue devices and processes, but agrees with his plea to return some technical specificity to the terms and their distinction. This surveying of the history of the debate is buttressed by looking deeply into the work of theoretical biologist Howard Pattee, who has, since the 70s, used biology to critique claims in computation, AI and A-life, around the adequacy of discrete and digital processes to embody biological processes such as intelligence and evolution. Central to Pattee's discussion is how the fundamental processes of life rely on the power of formal description and code, primarily through the directing force of the genetic code, but how such processes only ever tell half the story, and must be seen alternating and interacting with continuous dynamical processes that are both medium-specific and time-bound.

This thesis is offered as an act of cybernetic musicking – resolutely practical in orientation, and with a wide-ranging, trans-disciplinary theoretical framework. With the emphasis not on things but on ongoing processes in complex interaction with a world in constant becoming.

Research questions

Research questions informing both practice and theory are grouped into four related areas:

Analogue-digital
How might a combination of technical, historical and practice-based research, focused through commitment to artistic outputs in the domain of music technology, shed new light on the much used terms analogue and digital, and on the nature of the analogue-digital relationship?

Progress narratives and succession logic
There is a prevalent assumption that digital music-technological processes represent a progression from preceding analogue processes; how does this assumption stand up to a sustained, committed practice-based exploration?

Cybernetics
How might both practical and theoretical examination of technological musicking be buttressed by the now mostly obscured discipline of cybernetics, in particular the little known cybernetics of Gordon Pask?

Transduction and performativity
How might notions of transduction and performativity help us in explorations of complex technical environments supportive of the embodied production of music?

CHAPTER 1: CONTEXT (1) – KEY TERMS

Chapter summary

Cybernetics is introduced. Problems of definition are discussed. This thesis's engagement with the cybernetics of Gordon Pask is seen to be part of a recent upsurge of interest in Pask's work. Pickering's contribution to this re-evaluation is highlighted. A Paskian cybernetic methodology is adumbrated and seen to be a prescient precursor to contemporary notions of practice-based research. Pask's cybernetics is participant-oriented, focussed on processes in ongoing interaction (rather than 'things'), and stresses under-specified goals, rather than tightly defined goal-states. The practical nature of Pask's cybernetic method is highlighted – he saw himself as a 'philosophical mechanic', and built devices, systems and maverick computers throughout his career in order to test theoretical notions. A discussion of contemporary notions of practice-based research follows, highlighting the work of Schwab, Hacking and Barad. A detailed discussion of two other thesis keywords, transduction and performativity, rounds out the chapter. Performativity is an interventional act that brings forth a world; it is commitment in action. Transduction relates energy, information, patterns of growth, or other dynamical processes across media or between domains. It is a fundamental studio operation, and will prove invaluable in discussing tractable definitions of analogue and digital in the area of technological musicking. In the tape studio transduction and performativity come together at the moment that initiates the process of recording.

Cybernetics

> Knowledge is not some free-standing entity in its own right; it should be understood as threaded through practice, performance, in a world which cannot be itself reduced to knowledge. (Pickering, 2007, *44*)

When I started this doctoral project in 2013, armed with little more than a bunch of hunches and a desire to learn, I had little idea of what cybernetics actually is, other than a vague idea that it was something to do with robots, or computers, or both; a precursor of cyberspace, perhaps; inspiration for the Cybermen of Dr Who; that kind of thing. Such misconceptions are common, as I have discovered, following my own enthusiastic engagement with this deeply philosophical and highly sophisticated trans-disciplinary field. That these are misconceptions will become clear as we proceed, but for the moment I will note that as a composer

using technology for performance, installation and recording, I have come to see cybernetics as an extremely potent way of thinking through my artistic practice.

Cybernetics has a complex, multi-layered history, and since its heyday in the 50s and 60s has largely lain fallow in the popular consciousness; in the last twenty years or so Pickering, Cariani, Haque and others have done much to revive interest.[8] Such scholars see cybernetics continuing to offer important insights in the study of systems, communication and control, and many also see it as providing a useful prism through which to view much current artistic practice. Much of what follows is an attempt, on my part, at "becoming to know" (Pask, 1987, 32) the cybernetics of Gordon Pask, as it is his work which expresses the strongest resonances with, and relevance to, my practice. My work is therefore part of what architect Usman Haque describes as a recent "ground swell of interest in Pask's work by architects, artists and designers" (Haque, 2007, 54). What might once have been named 'cybernetic' art is now much more likely to be dubbed 'interactive', 'generative' or 'ecosystemic', but many of the concerns remain the same: the nature of both human and machine intelligence and learning; self-organising systems; autopoiesis; feedback; searching for emergence; human-machine interaction; evolutionary approaches.

Cybernetics, as a term, dates back to Norbert Wiener's seminal text, first published in 1948 (Wiener, 1961). The term is adapted from the Greek *kybernesis*, loosely 'the art of steersmanship'.[9] Put simply, cybernetics is the study of systems, control and communication, but precise definition is difficult, and contested: "What exactly is (or was) cybernetics? This has been a perennial ongoing topic of debate within the American Society for Cybernetics throughout its 50-year history" (Cariani, 2017, 120). Katherine Hayles' (1999) reading through of its "seriated" history, in support of her thesis that "we have always been posthuman", identifies three waves, the second of which broadly tallies with what has been more commonly dubbed second-order cybernetics – the 'cybernetics of

[8] Pickering (2011, 2009, 2007), Cariani (2017, 1993), Haque (2007). See also Hayles (1999), Green (2001), Bird and Di Paolo (2008), Boden (2008), Dupuy (2009), Fuller (2011), Penny (2013).

[9] 'Cybernetique' had earlier been used by Ampère in 1834 ("Cybernetics," 2018), but in a somewhat different context.

cybernetics', in which the observer cannot be wholly separate from the observed.[10] Andrew Pickering's recent work on cybernetics has a predominantly British cast, the two main players of which, Stafford Beer and Gordon Pask, are noticeably absent from Hayles' account.[11] The cybernetic focus of my thesis revolves primarily around the work of Pask, both in thinking about what cybernetics means, and in practical, musical exploration of areas that resonate with Pask's concerns. Pickering's work has been important in seeding a rich cybernetic pasture to which my own detailed study of Pask's work seeks to contribute.[12] Pickering views British cybernetics as adumbrating, in theory and practice, a performative, *nonmodern* ontology, which he contrasts with a *modern* ontology, representative of "science since the Scientific Revolution and of large swathes of contemporary commonsense" (Pickering, 2007, 44).[13] This modern ontology is "a vision of the material world as passive, something that sits around waiting for us, human agents, to represent it (to map it, describe it, theorise it, know it)" (ibid.). Whereas in the nonmodern ontology "the world – human and nonhuman – is a lively place of performatively interacting and endlessly emergent systems (of which we humans are just one sort)" (ibid.). Although we might well be cautious of such binaries (Pickering himself uses the terms "crude", "caricature" and "sketch" in relation to the above) there is an important sense in which Pickering is contributing to a rich and vigorous tradition of looking differently at cognition and representation, which includes Pask and Beer themselves, as well as Varela, Simondon, Latour, Haraway, Barad, Andy Clark and many others. "The history of British cybernetics offers us a different form of science and engineering, one that does not seek to dominate nature through knowledge" (Pickering, 2009, 470). The cybernetics of my thesis views control as steering a system one is a part of, negotiating contingency in a world of constant becoming.

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[10] "The distinction between the first- and second-order cybernetics depends […] on a change in attitude to the observer who, in second-order cybernetics, is understood to be both within the system being described and affected by it. That is to say, the boundary of what is being observed is no longer the same" (Glanville, 2004, 1384).

[11] Beer is not present at all, Pask has three brief mentions.

[12] I am equally indebted to other explicatory material: including Beer (2001); Bird and Di Paolo (2008); Glanville (2001a); Green (2001, 2004); Haque (2007); Scott (2001).

[13] Pickering follows Latour in his reading of 'modernity' (Pickering, 2011, 18).

Paskian cybernetic methodology

This thesis takes Pask's interpretation and adumbration of cybernetics as both theoretical underpinning and methodology.

> In dealing with *systems* of any kind, cybernetics is primarily concerned with establishing isomorphisms (one to one correspondences) rather than the validation of propositions that are true (or have a chance of being true) or else are false. The basic mode of argument and development involves analogy. Strict analogies of which isomorphism is a special case. The analogy expressed or represented in the language employed to account for events is a *metaphor*. In this sense, cybernetics is the science or the art of manipulating defensible metaphors; showing how they may be constructed and what can be inferred as a result of their existence. (Pask, 1975a)

Bernard Scott makes clear that in his three key works of the mid 70s (Pask, 1976, 1975a, 1975b) Pask was staking his claim on both his status as a cybernetician and on the status of cybernetics itself: "Pask's aim was not only to theorise as someone already committed to cybernetics but also to make clear, *once and for all*, what indeed are the foundations of cybernetics" (Scott, 1982, 2). In outlining a cybernetic methodology Pask makes clear the centrality of analogy, and it is interesting to note that in Pask's definition of cybernetics, above, only one from a list of keywords commonly associated with the discipline is present (it includes system, but omits control, communication, feedback, information, organisation, homeostasis, machine, computer, brain). For Pask, cybernetics demarcates systems, germane to a problem under investigation, and draws analogies between them that help illuminate operations. For example, Pask investigated the problem of *learning* by demarcating human learning from mechanised learning systems, and drawing analogies between them. That is very crudely put, as these are highly complex areas, but it indicates the approach. That it is *systems* that are the object of study is crucial, and presupposes a "systematic universe. There is a tacit assumption that things, objects, and other elementary entities are interdependent (rather than being isolated units, which is the assumption behind the majority of the sciences)" (Pask, 1975b, 15). This interdependency means that elementary constituents are not adequately distinguishable, not possible to cleave out of the ongoing flux of events, and so are not observable or meaningfully manipulable, whereas their *interactions* form systems, which *can* be observed and manipulated. But Pask is also clear that this observation and manipulation of systems has to be

participant. The initial systemic demarcation is already an interpretation that the cybernetician must acknowledge their own relation to, and part within. Further, Pask's cybernetic methodology is one of *process*, and so goals, which would have been thought of as "goal states" under Wiener's first-order cybernetics, come to be "interpreted as a class of intentions or processes. Under this caveat it is possible, without difficulty, to posit *underspecified* goals" (ibid., 14). Without underspecified goals, ground breaking work such as his electrochemical 'ear' would have been inconceivable (cf. p.101). The deliberately "ill-defined" (Cariani, 1993, 9) nature of underspecified goals allows for a richness of development and evolutionary potential difficult to achieve with fixed or pre-programmed goal states.

A Paskian cybernetic methodology operates at various different registers across this thesis. The thesis presents and manipulates various defensible *metaphors*, such as the mapping between analogue and continuous, and digital and discrete (though this has to be viewed from a position of contextual specificity, and does not hold in any kind of absolute way). The thesis uses *analogy* by, for example, studying the problem of performance in recorded music by demarcating the tape studio system and the DAW studio system and drawing analogies between them. This also involves questioning commonly held analogies (often posited as isomorphisms), such as those between a physical technical ensemble or piece of hardware (tape studio, compressor) and its software emulation (DAW, plug-in). The thesis demarcates *systems* throughout, and attempts to do this in a rigorous way (in particular, see chapter 3). It draws *distinctions* and makes *interpretations* (see chapter 2). Further, it is *participant-oriented* throughout (I can no more remove myself from this work than I can put this sentence into the third person). The physical systems built throughout the research manifest a richness in *interdependence* of elements, such that a *systemic*[14] treatment, as opposed to one that focuses on constituent elements, is the only way to gain any tractable purchase (see especially chapter 5 on modular synthesis, though interdependence is a constant throughout the practice). Finally, research trajectories are the result of following *underspecified goals* (hunches, intuitions, abductions); Varela calls this "laying down a path in walking" (Varela, 1986; Varela et al., 1993).

[14] "I.e., patterns of organization" (Pask, 1976, 12).

Underspecified goals are also key to modular synthesis performance piece *The Thing Breathed* (cf. chapter 5) and the concept of the self-organising studio (cf. chapter 3).

The theoretical approach is buttressed, and tested for fitness, by experiment, by building, by making: this is the practice itself. As Pask said: "By disposition, I like to think as a philosopher (or a philosophical psychologist). To justify this mode of thought and to implement the conclusions experimentally, it is often helpful to build physical systems" (Pask, 1976, 17). For example: chapters 3 and 6 question the commonly held isomorphism between the processes of tape studio and DAW *recording*. It suggest that this is a facile, or weak analogy because it does not sufficiently consider the relation of the performer to the conditions of performance; in fact what happens is that the performer in a DAW scenario tends to employ foresight of the possibility of post-performance editing to take pressure off the situation; performance in the tape studio tends to show a much greater commitment to the moment of performance. All of this is gleaned from hours of work in the studio, at the same time that I am thinking about the problem of the DAW,[15] one of the initial fuzzy hunches that launched this PhD. But theory and practice are *concurrently* executed (cf. chapter 3); neither takes precedence; they are circularly causal, in the language of early cybernetics. That the analogy between tape and DAW recording is weak is important to the overall theory because it is one of the things that is used in academic discourse on the recording studio (cf. p.116) to justify and normalise a succession logic that posits digital technologies as *historically* new/progressive/innovative (though that story is now old), *still* new/progressive/innovative (which is where we are now) and *future* new/progressive/innovative (which is where we *still* are). This thesis suggests alternatives to this view.

[15] "Any problem can be characterised as the need to bring about or satisfy a relation" (Pask, 1975b, 35). The relation here is between the production environment and what is produced therein.

Practice-based research

Matthew Fuller called Pask's devices "thought experiments carried out in hardware" (Fuller, 2011, 71), and there is a compelling historical continuity running from the practical cybernetics of Pask, Beer and others, to contemporary *practice-based research*, as scholarly investigation that generates insight and understanding through the outputs – artworks, performances, devices, processes – of an artistic or experimental practice. I would contend that much of Pask's work was practice-based research, as currently understood. Pickering concurs: "I am interested in ideas as engaged in practice, and at the heart of this book is a series of real-world projects encompassing all sorts of strange machines and artifacts, material and social" (Pickering, 2011, 4). Peter Cariani, musing on devices with emergent sensory capabilities says that "we need to return to Pask's earlier strategy of *building*, rather than simulating, actual physical devices" (Cariani, 1993, 11). My practice-based research agrees with the necessity to build physical devices, to operate as embodied agents engaged with the resistant materiality[16] of the real world, and in general, *not* to simulate.

Recently there have been many expositions of practice-based research (see, for example, Candy and Edmonds (2010) and the reference list therein), but one of the more interesting, and cogent in relation to my own artistic practice, is the one collected under the rubric 'experimental systems' by Michael Schwab, relating artistic practice to Hans-Jörg Rheinberger's theory of the same name (Schwab, 2016). Schwab denotes and compares "complete familiarity", "deskilling" and "reskilling" (ibid., 5) as manifest in much experimental artistic practice. In the context of *musique concrète*, complete familiarity would be that evidenced by original practitioners (Schaeffer, Henry, etc.). But my own familiarity with techniques of sampling, broadly believed to be isomorphic to *musique concrète* techniques, actually occluded my getting to know the historical technique. My inability to 'map back' techniques and processes of sampling onto its supposed 'forebear' indicated a misplaced assumption of isomorphism. In fact I had to

[16] I borrow this term from Hogg and Norman's edited special edition of Contemporary Music Review on 'Resistant Materials in Musical Creativity' (Hogg and Norman, 2013).

unlearn, or deskill, the sampling practices, and reskill myself with the actual physical techniques and processes in order to gain any purchase on the techniques, in order to create "epistemic things" (ibid., 7), or material objects in-themselves, which, through their creation, offer insights into both the embodied historical practice and a contemporary view on that practice.

Schwab draws extensively on Rheinberger's approach to scientific investigation, but is keen to fold artistic research as practice into the "practice turn in contemporary theory" (ibid., 5). Rheinberger's research into experimental systems serves as the relevant critical grounding for the attempt to "trace some links between experimentation and artistic practice – by comparing the laboratory and the studio, by focusing on material practice, by describing systems of creation, or by highlighting temporal or experiential dimensions" (ibid., 6). The work presented in this thesis embraces all four of these exemplars: chapter 3 links laboratory with studio in attempting to demarcate a cybernetics of the studio, explicitly linking Pask's lab-based experimental systems with my own studio seen as a self-organising system. Material practice is highlighted throughout: this thesis takes the position that digital simulation and/or emulation is not the same as the physical, material or analogue process being simulated, even though the distinction is commonly downplayed, overlooked, or occluded by skeuomorphism.[17] Pattee's concept of *medium-dependence* is also apposite here.[18] Systems of creation are examined in chapters 5 and 6, and again, Pattee's views on the *creation* of symbolic or formal representations as being essentially non-formalisable, occuring in real-time in a continuous dynamical milieu, are important; as is Pask's views on abduction (analogous though not identical to Pattee's views, cf. p.46). Finally, temporal or experiential dimensions are

[17] A skeuomorph is "a design feature that is no longer functional in itself but that refers back to a feature that was functional at an earlier time" (Hayles, 1999, 17). A common everyday example is the camera click sound on smart phones, which samples the sound of the shutter opening and closing on a mechanical camera; the smart phone has no such shutter, and the sound, whose actual function is to say 'photo taken', could equally well be a beep. Examples in the DAW often present digital emulations dressed in the clothes of hardware, such as the many software emulation of classic compressors like the LA-2A. The DAW itself presents a skeuomorphic emulation of the tape studio (cf. chapter 6).
[18] Theoretical biologist Howard Pattee has been deeply influenced by cybernetics. He is discussed in chapter 2.

highlighted throughout the thesis by a general concern with process, with becoming, or ontogenesis, through performativity and transduction, and in the creation of participant observed systems.

In discussing the knotty issue of scientific realism within the practice and philosophy of science, Ian Hacking also stresses the importance of insights wrung from experimentation, arguing that we must pay at least as much attention to doing, to practice, as we do to theorising. Hacking's overriding contention is that the philosophy of science, with associated debates about the nature of scientific realism, should engage much more deeply with experiment (on which it has little to say) than it does with theory (on which is it voluminous). He councils us: "Don't just peer: interfere" (Hacking, 1983, 189), a plea for performative action in the world which acknowledges experiment as vital to the creation of insight. He goes to great lengths to redress the balance that has been upset by a "single-minded obsession with representation and thinking and theory, at the expense of intervention and action and experiment" (ibid., 130). Like Pickering and Barad, who both propose a turn from representation to performativity, Hacking suggests a "turn from representing to intervening" (ibid., 145). He believes that the route back to a sensible scientific realism will come from our experimental practices with their concomitant intervening: "We shall count as real what we can use to intervene in the world to affect something else, or what the world can use to affect us" (ibid., 146). I do not engage here with debates about scientific realism, but nevertheless find the tenor and thrust of Hacking's argument apposite with regard to practice-based research.

Karen Barad draws on Hacking's critique of representationalism in positing a turn from representation to performativity. Like Pask, she distrusts the numinous observer of classical physics: "A performative understanding of scientific practices, for example, takes account of the fact that knowing does not come from standing at a distance and representing but rather from *a direct material engagement with the world*" (Barad, 2007, 49). This focus on material engagement is taken here to be primary to any practice-based investigation, which will be performative, interventional and experimental.

Transduction and performativity

The concepts of transduction and performativity are central to this thesis. Both terms have rich histories in scholarly work of the last 70 years and are fundamental to my thinking, making and musicking in a variety of ways.

Performativity is an interventional act that brings forth a world. It is the bringing into being of meaning, in a shared universe of discourse, through action, utterance, performance. It is real-time semantic activity, commitment in action. In J.L. Austin's original usage it is an utterance that makes a difference to the worlds of utterer and witness: 'I do'. Barad points out how, in Judith Butler's usage, it becomes an active construction of identity: "Butler proposes that we understand identity not as an essence but as a doing" (Barad, 2007, 62). For Pickering and Barad performativity is an alternative to representation. For them, in their different ways, it is engagement with a world in perpetual becoming; it rejects an idea of a 'fixed' world, 'out there', that can be explained, controlled, put to use, through symbolic representation and (conventional) scientific explanation. "Unlike representationalism, which positions us above or outside the world we allegedly merely reflect on, a performative account insists on understanding thinking, observing, and theorizing as practices of engagement with, and as part of, the world in which we have our being" (ibid., 133). Thus Barad's position aligns with Pask's participant observer (cf. p.60). Pask does not use the term performative, but I would argue that his theory is "proto-performative" in much the same way as Barad claims for Niels Bohr (ibid., 31). Discussing the "situated" nature of knowledge generated by participant observers Pickering says that: "The shift from a representational to a performative idiom for thinking about science, and from epistemology alone to ontology as well, is the best way I have found to get to grips with the problematic of situated knowledge (and much else)" (Pickering, 2011, 26), and he explicitly links a "performative epistemology" with an "ontology of becoming" (ibid., 519). Barad similarly rejects an exclusively epistemic approach, and directly links knowing with being, coining a conjoined "onto-epistem-ology" (Barad, 2007, 185). She goes on to stress the importance of our own responsibility towards the part we play in such becoming through a performative "ethico-onto-epistem-ology" (ibid.). From this position there is no

possibility of dominating a world through rational explication, since this type of penetration is always one step behind a changing world, and implies a separation between knower and world that a performative participation precludes. Rather, performativity suggests one must 'go with' the dynamics of a system, hitching a ride, negotiating contingency, with the possibility of steering trajectories. In this sense, performativity itself is resolutely second-order cybernetic: the observer *must* be part of the system; there is no possibility for any absolute, numinous, objective observation. Going with the flow means accepting that one's presence and participation alter the dynamics of the system. In this sense performativity is closely linked to ontogenesis, as theorised by Simondon, as a constant and ongoing individuation (Simondon, 2016). Performativity is the *act* of inscription, and not what is written. It is writing directly onto the world as it becomes, a co-origination of meaning, or "codependent arising" as Varela et al. hear it (1993). The results of performative action are dynamic, metastable states of being: 'I now pronounce you man and wife'; they are "basins of attraction" (Cariani, 1991, 112) that configure, calibrate and constrain further performative action.

Transduction, like analogy, involves a similarity and a distinction. It *relates* energy, information, patterns of growth, or other dynamical processes *across* media or *between* domains. In physics it is the conversion of energy from one form to another. Simondon, who made the concept a cornerstone of his philosophy of individuation, gave a much broader definition than this, and his simplest example is of the growth of a seed crystal in a saturated solution. The crystal growth occurs on the surface, and each layer structures and constrains growth of the next layer through progressive iteration. "Hence the transductive process occurs at some kind of limit or interface between different orders… From the process of individuation results both a new kind of individual – the crystal – and an *associated milieu*… the now somewhat diluted solution with a different solubility" (MacKenzie, 2003, 12). Adrian MacKenzie builds on Simondon's treatment of transduction: "The hallmark of a transductive process is the intersection and knotting together of diverse realities" (MacKenzie, 2006, 13), particularly the emphasis on ontogenesis, or becoming: "Every transduction is an individuation in process. It is a way something comes to be, an ontogenesis" (ibid., 15). Transduction is about bringing different realities, domains, environments

together, through a relation that structures as it differentiates. It is a bringing into being, a becoming.

Transduction is also vital to this thesis, since it is one of the essential ingredients of any tractable definition of analogue or digital recording. The ultimately insoluble problem of defining the terms analogue and digital is discussed at length in the next chapter, but for the moment I note that the best definition I can find for analogue or digital recording is whether the terminal transduction leads to the audio being stored in a continuous or discrete form. The process of digital recording involves an analogue to digital converter, which transduces a continuous electrical signal into a discrete numerical code; its terminal transduction leads to a discrete stored signal. Analogue recording will involve a terminal transducer – such as a tape head, or a stylus to inscribe a groove onto a record – that leaves a continuous trace that is an analogue of whatever was fed into the transducer. The analogy relation is not enough on its own for a definition of an analogue recording since it applies equally well to a digital recording, but the fact of the continuous nature of audio on magnetic tape, or on vinyl, is the key thing that distinguishes it from a digital recording. The ramifications of this distinction will be discussed throughout the thesis. This way of defining the analogue-digital distinction will not port over to computation, or watch, or what have you.

Transduction is a fundamental studio operation. As Allen Strange noted: "One of the major processes of electronic music is that of 'transduction,' the transfer of power from one medium to another. A transducer is a device which reacts to one type of wave (voltage, light, pressure, current, etc.) by transforming that wave into an analogous wave of another medium" (Strange, 1972, 108). Jonathan Sterne also reflects at length on the importance and significance of transductive processes in "audile" technologies (Sterne, 2003).

In telegraphy, transduction converts an utterance into a discrete (Morse) code; its passage through various relay stations leaves the message unchanged until it is decoded at its destination, another transduction. In telegraphy, if the message is changed, either during the bookending transductions or in the intervening

temporal or spatial passage, then the system is in error. But there is another, essential transductive process here, a performative one, in the *composing* of the original utterance, such that its later dual transduction, into and back out of code, does not change the nature of the message. The telegram tends to be short, pithy, unambiguous. The economic constraint of charging per word further feeds into and constrains this originary performative transduction.

A fascinating contemporary example of transduction constraining performativity can be seen in the practice of the 'human microphone', used by the Occupy Wall Street movement in their occupation of Zucotti Park, in New York, but later taken up by other protest movements. Responding to a ban on unlicensed electrical amplification in public spaces in New York, the human microphone operates via 'people power'. A speaker, standing at the centre of concentric rings of human 'amplifiers', wields the metaphorical microphone by speaking short phrases that are repeated by the wider group, outward in iterating circles of human amplification. To start the process, or to reset it if it goes wrong, the speaker says 'mic check', repeated by the listening crowd: 'MIC CHECK', then continues with short phrases that are repeated by the crowd.[19] The human microphone is discussed at some length, and as a transductive process, by Suzanne Cusick in 'Musicology, Performativity, Acoustemology' (Cusick, 2017). Cusick concentrates on the political and transgressive potentials of this performance, but just as interesting for me, is the highly contingent tuning process that goes on between speaker and 'amplifier'. If the discrete messages are not calibrated in the right way then the whole system breaks down. If the utterance to be broadcast is too long then the 'microphone' forgets the details and the transmission breaks down. If enunciation is not clear, if overly technical language is used, if concepts are not broadly shared, then the whole system has to be reset, with speaker paying closer attention to the effectiveness of transmission. Thus speaker and amplifier are in a direct, contingent, mutually constraining, transductive relationship, and it is this kind of multi-directional, contingent, concurrently executed transduction that this thesis is particularly interested in.

[19] The best way to get a feel for what is happening with the human microphone is to watch videos such as https://www.youtube.com/watch?v=tvJqLo_o7AM.

In the tape studio (cf. chapters 3 and 6) performativity and transduction come together at the moment of pressing 'record'. This pivotal juncture, at once cusp, crux and crunch, is a discrete, catalytic switch, a point of transduction between two experiences of time: from rehearsal to performance, from coded description to performative execution. On one side of this temporal transduction is a discontinuous, halting process that accumulates readiness, that entrains gesture, that alternates rapidly between discrete description (plans, notes, memories) and continuous expression (practice, performance, interpretation) in preparation for the keen edged transductive moment that initiates 'recording'. On this other side of the divide planning, rehearsal, memory are mustered in support of continuous becoming, codependent arising: the performance itself, with its commitment to meaning in the moment of its making.

Of course, this heightened commitment *can* occur with digital recording, but I will argue that this is one of the problems with the DAW and digital audio in general: there is a tendency towards an evacuation of meaning from the process of *recor∂ing*, a lack of commitment to the performative unfolding. This occurs because the result of the recording tends to be just so much more code, with all the accompanying possibilities for manipulation, reinterpretation, rejigging, in fact jiggery-pokery of all kinds. Performers and engineers are well aware of such post-performance possibilities, and so the recording tends to be seen as one more coded element in the gamut of production possibilities the DAW affords; this more 'constructive' approach tends to defer commitment until *after* the recording process. All of this will be explored in depth in chapters 3 and 6.

But before we get there it will be necessary to put some fresh flesh onto the old bones of that hoary beast: the analogue-digital distinction.

CHAPTER 2: CONTEXT (2) – THE ANALOGUE AND DIGITAL WHAT HAVE YOU

Chapter summary

Analogue and digital are presented as complementary, and the axiom *analogue and digital always and only coexist* is introduced. Historical and technical definitions mainly revolve around a mapping of analogue onto continuous and digital onto discrete, but recent usage in popular culture diverges by defining analogue as that which exists outside a computer (opposite to digital). None of these definitions adequately cover the diversity of disciplinary, contextual, historical and technical usage. The history of the analogue-digital distinction is explored by considering canonical texts from beginning, middle and end of its 80 or so year history. Roots of the debate are traced to the rise of practicable computational devices in the 1940s and coincide with the birth of cybernetics. One extended debate from the Macy Conferences on cybernetics is examined in detail. Links with biological, cognitive and physical phenomena are explored. Interpretation and level of description are seen to be key to usage, but participants are unable to agree on a tractable definition of the distinction itself. Philosophical treatment of the distinction from the middle of the history is presented: Haugeland's exploration shores up the notion that the two terms are 'substantive-hungry' – they need to take a referent in order to be meaningful. Sterne's recent exploration of the distinction alerts us to the way popular culture's definition of analogue has changed to mean everything outside of the computer. Transduction is seen to be an essential element of all attempts at definition with the audio realm. This thesis agrees with Sterne's plea to return some technical and contextual specificity to usage of both terms. The history is expanded upon through a detailed look at the work of Howard Pattee, who showed how continuous and discrete processes in life and biological evolution are necessarily complementary, how the appeal to the sufficiency of the discrete in ambitious digital computational areas such as AI and A-life is flawed, and how the frequent *alternation* between discrete, symbolic, formal, time-independent processes, and continuous, dynamical, time- and medium-dependent processes is essential to creative processes of life such as cell formation and evolution. The final section of the chapter sketches how Pattee's ideas of this essential alternation between continuous and discrete might be applied to creative work such as songwriting.

Analogue-digital

The analogue and digital 'what have you' is a shorthand adopted in this thesis, borrowed from Haugeland (see below), that serves two related functions: (1) It indicates that both the terms analogue and digital, as well as a conjoined analogue-digital, must take referents, substantives, nouns, noun phrases, or what have you, in order to have any meaning. (2) What have you refers to all the things analogue and digital *may* be: devices, processes, signals, representations, what have you, without deliberately stating *what* process, device, etc. they *do* take, while acknowledging that they *must* take such a process, etc. in order to *be* meaningful.

The dash in analogue-digital means both 'and', and 'complementary relationship'. Central to this thesis is the idea that analogue and digital are complementary, that they *always and only coexist.*[20] There has been much hyperbole, ramped up exponentially in the last twenty years, around the term digital, both in relation to AI, which is, for most people, associated exclusively with digital processes, and in commonplace phrases such as digital culture or digital age. This puts the pairing analogue-digital on an unequal footing, with analogue positioned in various ways as digital's 'other': as predecessor, in narratives that rely on a succession logic that valourises digital as new/innovative/progressive; as all that exists outside of the computer (cf. p.38); or, when dealing with analogue technologies' stubborn refusal to quietly obsolesce, as hipsterish retro-futurist nostalgia.[21] The position of this thesis is that such oppositional binaries are in urgent need of questioning and as such we will need to look, once again, at what the terms analogue and digital actually mean, from both a contemporary and a historical perspective. We will come to a position that refuses such commonplaces as 'digital revolution', 'digital age' or 'digital present' with their concomitant 'analogue past', and that asks that we take seriously the idea that these two terms are complementary, that neither

[20] I borrow this phrase from Buckminster Fuller, who used it of complementary phenomena such as tension-compression, or convex-concave: "We learn experimentally that tension and compression always and only coexist" (Fuller et al., 1982, 357). Fuller's work also manifests a philosophically minded practice-based approach (cf. chapter 1), but is outside the scope of this thesis.

[21] See also Born (1995) on progress narratives centred on 'vanguard' digital technologies at IRCAM, and the related 'othering' of both analogue technologies and popular music.

one can exist without the other, and that drawing a distinction between them, positing any situation, temporality, device, or process as one or the other, is always already an act of *interpretation*, and cannot therefore exclude the observer from the act of distinction drawing.

There seems to be broad agreement, in both popular and academic discourse, that we have been through a digital revolution and have now entered a digital age. Examples (and devices) abound. A very partial illustrative list might include: *Academia*: digital humanities, digital archives, digital history, digital arts, digital media, digital lives, digital memory; increasingly it seems that digital can be prepended to any discipline or area of scholarly investigation to bring it into the digital present, give it currency, make it 'with-it', and give it increased likelihood of funding. *Business*: digital solutions, digital innovation, digital entrepreneurship, digital transformations. And of course the much discussed contemporary phenomenon, without which any discussion of a digital present would be incomplete: *social networking* and a host of associated digital cultures. In the popular press there is talk of reactions to such ubiquity in the form of digital fatigue and the need for a digital detox.[22] Scholarly reaction takes many forms, such as recourse to the periodising prefix 'post', as in post-digital (Cramer, 2015).[23] The problem, from the perspective of this thesis, is that the various positionings of 'post', fatigue, reactions against, nostalgic turns, analogue renaissance(s), fail to confront, and indeed support, a periodising succession logic that aligns digital with the new, the present, and often – in the blissfully optimistic, or anxiously dystopian, views of convergence and singularity – with the future.

[22] Which can manifest in all kinds of ways, usually as an injunction to cut down on 'screen time', an example being the huge growth of adult colouring-in books: 12 million sold in 2015 (Halzack, 2016).

[23] Although the hybrid nature of much work that comes under the rubric of post-digital is welcome, and the wish to move out of the exclusive domain of digital computation into wider networks involving physical, acoustic, or analogue processes aligns with much that this thesis supports, the term itself is highly problematic, since it normalises ideas of historical succession that the following exploration of analogue-digital will question.

A foray into the history of analogues and digits[24] will be necessary to lend some support to the position outlined here: (1) the succession logic whereby a digital present implies an analogue past has no actual basis in either fact or history; (2) the analogue *versus* digital debate implies an opposition which is not born out through either a technically specific or philosophically acute view (Peters, 2016, xxxii); (3) faith in a digital future is just that: faith. Pattee calls this "faith in formalism" (Pattee, 1993, 7); (4) progress narratives woven into 'the debate' benefit an avaricious technology industry that relies on planned obsolescence and a rhetoric of novelty and innovation (Sterne, 2007).

Schonbein (2014, 415) identifies the "standard interpretation" of analogue and digital: analogue = continuous, digital = discrete. Schonbein draws the distinction along representational lines, but it also applies, throughout the wider literature, to many other substantives: device, signal, medium, process. Although these equivalences should be treated with some caution,[25] they do capture something important to the distinction as it has been historically drawn. Discrete here refers to the stepped, the either/or, the quantised, the formalisable; continuous to the smooth, the more or less, to approximation. The following will complicate Schonbein's standard interpretation, primarily by putting interpretation itself at the core of the act of making a distinction, demarcating a system, delineating a boundary, or however you like to cut it. This thesis does not say that analogue *is* continuous, and digital *is* discrete; rather, the following analysis will suggest that no absolute, one-to-one isomorphism will ever be sufficient to categorically demarcate the analogue-digital distinction, but that in certain situations this will be a useful shorthand, or way in, to how the distinction may operate.

Lists of canonical devices commonly include many of the following: *Analogue*: slide rule, scale model, map, phonograph, microphone, analogue computer, cassette.

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[24] The phrase "analogs and digits" is used as a section header in Nelson Goodman's *Languages of Art* (Goodman, 1976, 159). His philosophical account of the analogue-digital distinction is important to the history of these terms, and was highly influential to Haugeland and others who subsequently explored the distinction.

[25] See for example, Fischer: "Glanville [personal communication with Fischer] however cautions that digital and discrete are not equivalent. He associates discrete with distinction drawing as presented by Spencer-Brown (1997) and digital with using a basic unit in terms of which phenomena are measured" (Fischer, 2011, 1006).

Digital: finger, abacus, alphabet, switch, typewriter, digital computer, CD, mp3. In fact, fingers offer a fistful of examples from both sides of the divide, suggesting both the necessarily conjoined nature of the two terms, and emphasising the hand's unique and primary position in our cognitive apparatus, and in our ways of describing and knowing the world. On one hand, fingers are the exemplary discrete counting device, and we are reminded that fingers *are* digits. The finger also points up its primacy in the activity of 'pointing at' or indexing (Peters, 2016, 94); both counting and indexing are activities squarely on the digital wing. The other, analogue, hand[26] is used for measuring and approximating: directly measuring the distance between thumb and forefinger, or offering commonly understood approximations, four and a half hands high, or the 'inch' as half a thumb. The hand and its fingers are neither digital nor analogue, but happily take on representational duties, or function as descriptive exemplars, for either side.

Metronome – complementarity of continuous and discrete

Before launching into a detailed historical examination of the terms, we can briefly give an example of analogue-digital complementarity in the form of the metronome. The pendulum swing of the arm is clearly continuous, and the 'click', derived from the toothed escapement, is clearly discrete.[27] Here we see a complementary relationship where, from one perspective the continuous is transduced into the discrete, and from another the opposite directionality holds. Actually, both hold in a mutually reciprocal circular causality: the toothed gear of the escapement injects a small amount of potential energy, held in the spring, once per half cycle, into the pendulum, by nudging it at the extreme of each half oscillation. Gravity acting on the pendulum provides most of the energy, but the push from the escapement counteracts the friction that would eventually damp the oscillations of the pendulum if left unaided. The two processes, continuous swing

[26] There is also a tentative suggestion of handedness here: the 'right' hand opposed to an 'other' or 'cack' hand, designated *gauche* in French and *sinistra* in Italian (yes, I am a southpaw). On handedness (chirality) in chemistry, see Pattee and Kull (2009, 313).
[27] From the perspective of a human using a metronome to demarcate a pulse. From the perspective of a digital recording, where one could visually zoom into the waveform of a single click, one would see a (short) continuous signal. Again, interpretation is key.

of the pendulum and discrete, click-stop motion of the escapement, form a circularly causal system, marrying potential, kinetic and gravitational energy into an effective timekeeper. This is just the same process as when someone times the pushes on a playground swing so that the swing maintains constant height through each cycle, or indeed the swinger uses their own body weight to keep the swing in motion against friction of the air. The pushes are discrete (viewed from the perspective of single, isolated injections of energy, from the perspective of the muscles in the body it would appear continuous), the oscillating motion of the swing is continuous (at least to our eyes and at a level of description that is useful).

The historical discussion of the analogue-digital distinction that follows establishes an 80 or so year history, and looks at theoretical discussion from the beginning, the middle and the end of this period.

Cybernetic origins of analogue-digital

Although the terms analogue and digital are individually much older than the 1940s, this is when their conjoined significance first manifests, primarily as a result of developments in computer technologies. When we take a historical view of the analogue-digital distinction, we find that its origins coincide with the birth of cybernetics. The nature of analogue and digital computation (in mind and machine), communication, signals and, to a lesser extent, representation, was debated at length at each of the ten Macy conferences that established and formalised the discipline that was, at that stage, only just beginning to know itself as cybernetics (Pias, 2005, 545).

In his address to the 5th (1950) conference, neurophysiologist Ralph Gerard picks up a subject that had already been debated several times before, "digital and analogical mechanisms in the brain" (Gerard, 2016, 172). The attempt to establish analogies between brain functioning and the nascent field of machine intelligence was absolutely central to all the Macy conferences, and to the establishment of cybernetics. Gerard makes clear that he believes that the emphasis on perceived

digital aspects of the nervous system was too heavily skewed, at the expense of insights that could be wrung from analogue processes: "I personally think that digital functioning is not overwhelmingly the more important of the two, as most of our discussions would seem to imply" (ibid.). In response to Gregory Bateson's wearied comment "I am a little disoriented by the opposition between analogical and digital" (ibid.), Gerard responds with something worth quoting at length to indicate that the tenor of the distinction has not really changed at all in the intervening 80 odd years in technical and philosophical writing, even if, as Sterne notes (discussed below), popular culture's definitions have diverged quite markedly.

> The picture that I have of analogical and digital, owing to the expert tutelage that I have received here, primarily from John Von Neumann, is this: an analogical system is one in which one of two variables is continuous on the other, while in a digital system the variable is discontinuous and quantized. The prototype of the analogue is the slide rule, where a number is represented as a distance and there is continuity between greater distance and greater number. The digital system varies number by integers, as in moving from three to four, and the change, however small, is discontinuous. The prototype is the abacus… The rheostat that dims or brightens a light continuously is analogical; the wall switch that snaps it on or off, digital. In the analogical system there are continuity relations; in the digital, discontinuity relations. (ibid.)

Von Neumann's position in the ensuing discussion is complex, balanced, and anything but the clear endorsement of digital preeminence that one might expect from the 'father' of the digital computer: he agrees with Gerard's position that the digital situation may well not be the most important one in the nervous system: "It is very plausible, indeed, that the *underlying* mechanism of the nervous system may be best, although somewhat loosely, described as an analogical mechanism" (ibid., 176). He allows that the underlying substrate of any digital computer will be a continuous electrical current, an analogical concept, and that "both for the man-made artifact as well as for the natural organ, which are supposed to exercise discrete switching actions, these 'discrete actions' are in reality simulated on the background of continuous processes" (ibid., 177). However, it is not at the level of simple components that useful analysis should be conducted: we need to look at how larger complexes of such elements connect together. Von Neumann acknowledges that little is known about the extent to which the nervous system uses coded (i.e. digital) messages, and is clear that such coded messages almost

certain coexist with hormonal messages, "which have a 'continuum' and not a 'coded' character" (ibid.). Importantly, "there seem to be very intricate interactions between these different systems" (ibid.). Internal biological informational processes, viewed systemically, will alternate between complementary continuous and discrete modes of operation. We will meet this idea again in the context of the thinking of Howard Pattee, but it is useful at this stage to note that von Neumann was perspicacious in this regard. "The last question that arises in this context is whether any of the coded ways in which messages are sent operate in any manner similar to our digital system. If I understand the evidence correctly, it is nonexistent in this regard" (ibid.). Thus, for von Neumann, although the digital computing machine may be best suited to certain types of functioning, we shouldn't make the mistake of thereby assuming isomorphism between the discrete architecture of the digital computer and the brain or nervous system, as 'strong' AI and its associated computationalism would go on to assert (see Boden (2008), Varela et al. (1993), Winograd and Flores (1987)).

Contributing to the debate, Norbert Wiener counsels constructing computing machines which are "in part digital and in part analogical", since that is a freedom that he "profoundly believe[s] to exist in the nervous system" (Gerard, 2016, 176), and which we should take advantage of in our constructions of automata and thinking machines. Wiener aligns himself with later currents in philosophical thinking, particularly in reaction to AI, that certain aspects of human intelligence, such as learning, creativity and intuition are not possible to simulate in wholly digital environments. "I feel that the machines we build in the future for a great many purposes should take advantage of nondigital ways of modifying the threshold of digital machines. I do not see any reasonable explanation for the learning process which does not take advantage of these things" (ibid.).

There is a sustained and lengthy portion of the whole discussion devoted to nailing down the definitions of analogue and digital, and which, in the end, fails to hit upon something everyone present can agree on. Bateson notes "that the analogical model might be continuous or discontinuous in its function." He considers the *analogy relation* underlying the term analogue as one of the chief causes of

difficulty. Von Neumann replies: "It is very difficult to give precise definitions of this, although it has been tried repeatedly. Present use of the words 'analogical' and 'digital' in science is not completely uniform" (ibid., 181). Analogue devices, though, have a

> common trait: certain physical quantities that have continuous motions are represented by similarly continuous processes within the computing machine. Interrelationships are entirely different in a digital model… The digital procedure is usually a human artifact for the sake of description. Digital models, digital descriptions arise by treating quantities, some of which or all of which are continuous, by combinations of quantities of which each has only a small number of stable (and hence discrete) states – usually two or three – and where one tries to avoid intermediate states. (ibid., 181-2)

Thus the very human acts of representing and interpreting ('for the sake of description') are key to the drawing of the distinction, and attempts to cement the distinction through appeals to biology miss this crucial fact. As with any act of interpretation, the position of the observer must be taken into account.

John Stroud contributes to the discussion with a very clear indication of the importance of this act of interpretation, and, at a fundamental level, of the importance of the conjoined, complementary nature of the two terms: "I know of no machine which is not both analogical and digital, and I know only two workable ways of dealing with them in my thoughts. I can treat them as analogical devices, and if this is a good approximation I am happy. I can treat them as digital, and if this approximation works I am happy. The devils are generally working somewhere in between" (ibid.,182). This 'devil in the details', this 'in between-ness', is why the act of interpretation is so crucial, as it allows us to simplify, to make workable or usable systems which are otherwise too complex to be tractable. As Wiener says later in the discussion: "I say that the whole habit of our thinking is to use the continuous where that is easiest and to use the discrete where the discrete is the easiest… One thing that we cannot do is to take the full complexity of the world without simplification of methods. It is simply too complicated for us to grasp" (ibid., 197).

Again, on the subject of the complementarity of analogue and digital, Fremont-Smith contributes: "Capillary flow is continuous and the heartbeat is intermittent;

it seems we have a perfect example right there. You cannot take any point and decide when the shift from the intermittency of the heartbeat to the continuity of the capillary flow takes place" (ibid., 198). This is analogous to the example of the metronome, given above, where continuous and discrete processes are clearly conjoined through intimate coupling, and where neither process can be said to take precedence or be in control of the other. It is this sense of mutuality, of codependence, that has been lost in proselytising rhetoric that posits the digital as superior to, posterior to, progressive of, the analogue. The distinction and its associated 'debate' was there, fully formed, right at the beginning of the use of the terms analogue and digital. Wiener puts the original use of the terms, and their distinction, "at about 1940" (ibid., 192), just ten years before the discussion under consideration here. The OED's etymology of both analogue and digital concurs with this dating (see Sterne, 2016). Rather than analogue technology being an 'anachronism', as current debates in music technology would have it (see chapter 6), and as various commonplace positions around 'vintage' equipment, hipster appropriation, or 'technostalgia' might suggest, the anachronism is to posit *either* term as newer than the other. This thesis takes the position that both terms must be seen as complementary, mutually co-specifying, conjoined, *always and only coexisting*. The evidence from the technically and philosophically acute discussions of the terms at the Macy conferences supports this view, but somewhere along the line, in popular culture as well as in serious, informed scholarly debate, the terms have become aligned with historical 'eras' (and very short ones at that) that occlude this mutuality.

Analogue and digital what have you: substantive-hungry terms

Some 30 years later, philosopher John Haugeland, in attempting to answer the question of whether "any analog computer can be digitally simulated" (Haugeland, 1981, 213), comes up against the same problem as the Macy conferees: how to actually *define* the terms analogue and digital, and devotes the majority of his paper 'Analog and Analog' to this "tricky and interesting" problem, and justifies his "curious title" by positing both "stricter and broader senses of

'analog'" (ibid.). It is, as ever, the analogue half of the distinction that proves to be the sticky one.

What I would like to say first, in relation to this difficulty of definition, and if one wishes to maintain some sense of technical specificity, is that the terms analogue and digital cannot really stand in isolation (either separately or in relation to each other). Although recently there has been much recourse to 'the digital' and a somewhat later, reciprocal 'the analogue', as units of language the terms are "substantive-hungry", as philosopher J.L. Austin said of the word 'real': they are terms that need to take a noun or a noun phrase (Austin, 1979, 68).[28] Austin argued that the word 'real' cannot stand in isolation; in order to have any meaning it needs to take a qualifying noun, such as world, time, Rembrandt, cream, diamond, leather, ale, etc. In a similar way, analogue and digital prepend in technical writing to such substantives as: device, signal, representation, media, computer, electronics, watch, recording. Haugeland is aware of the problems that arise from treating either term in isolation, thus gives his canonical list of digital *devices*: "Arabic numerals, abacuses, alphabets, electrical switches, musical notation, poker chips, and (digital) computers" (Haugeland, 1981, 213). He footnotes: "I resort to the non-committal 'devices' because anything more specific seems wrong; thus (as the above list shows) not everything digital is a representation, a process, a computer, a machine, or what have you" (ibid., 225). I have borrowed this off-hand 'what have you' as non-specific placeholder for all the substantives analogue and digital *may* take, and to indicate that they *must* take one.

What connects Haugeland's diverse digital devices together is both the discrete, quantised base, and the idea that they manifest a coded, or formalised aspect. They operate without recourse to a specific substrate or medium. Arabic numerals

[28] See also Hacking (1983). Austin also calls 'real' a 'trouser-word', a "genially sexist" (Hacking, 1983, 33) way of noting that it is the "*negative* use [of real] that wears the trousers" (Austin, 1979, 70). I'll say no more about that here, since I don't think analogue or digital are trouser-words, but will note that the lyrics of my song *Substantive-Hungry Trouser-Word* (see http://euterprise.com/index.php/music-research/euterprise-ep/euterprise-ep-lyrics-songwriting-demos/substantive-hungry-trouser-word-lyrics/) play on Austin's original designation.

work perfectly well in sand, on paper, on screen and happily move unchanged between them; they are medium independent (cf. Pattee, below). To be sure, complex digital architectures, such as software written for a particular operating system operating on tightly defined hardware, do not 'port across' easily, but in theory such algorithmic processes could be written in stone.[29] Haugeland notes three qualities of "theoretically interesting kind" (ibid., 213) for digital devices: (1) Flawless copying: the countless perfect copies of Shakespeare sonnets.[30] (2) Complexity forms from simple components: "all classical symphonies are scored with the same handful of basic symbols" (ibid., 214).[31] (3) Equivalence across media: "the sonnets could be printed in italics, chiselled in stone, stamped in Braille, or transmitted in Morse code – and nothing would be lost" (ibid.).

For Haugeland "analog devices comprise a motley crew", and he is "not at all confident that a satisfactory definition is possible" (ibid., 220). This is something we frequently witness as we survey the diverse literature of the analogue and digital what have you: the digital half of the pairing exhibits a clear cut, all or nothing, formalisable definition, and the analogue wing invites approximation, 'more or less' clarity, and a continuum of possible interpretation. In other words, each term's definition seems to exhibit the qualities of its referent's form and function – the terms are exquisitely self-referential in an imbalanced, mutually exclusive but codetermining relationship. Haugeland points this up by noting, as he does with digital, three salient common features of the analogue device: (1) Smooth or continuous variations: no steps, gaps or click-stops; between two values there will always be theoretical intermediate points, even if the resolution of the carrying medium obscures a finer grained observation. (2) "Within the relevant variations, every difference makes a difference": the tiniest adjustment of a knob changes the setting; "not only are all variations allowed, but they all

[29] Though see Haugeland (1996, 121) on the importance of various levels or layers of description that such a writing would have to inhabit.
[30] Digital audio also has this property, and this infinite replicability, especially when it manifested in the small size of the mp3 coupled to the mobility of the internet, came to terrify and in many ways cripple the music industry, which is ironic when one recalls that one of the key benefits to the industry of the introduction of the CD was the ability to resell digital copies of individuals' already existing vinyl record collections.
[31] Also in evidence in work on emergence in cellular automata and neural networks.

matter" (ibid., 220).[32] (3) However, "only certain 'dimensions' of variation are relevant" (ibid.); it is irrelevant whether a slide rule is made of metal or bamboo, it will still afford comparable (approximate) calculations. It is this last feature that makes for the difficulty of definition, for this orthogonal "dimensionality" suggests a "'second-order' digitalness" (ibid., 222): variation is continuous across one or more dimensions, but the number of dimensions will be fixed and limited. The black and white photograph has "exactly three orthogonal dimensions: horizontal, vertical, and gray scale" (ibid.); or the analogue computer, "with its electronic adders, integrators, multipliers, inverters, and the like, each as discrete and determinate in type as any mathematical symbol, and their circuit connections as well-defined as the formation of any equation" (ibid.). Haugeland calls this the digital set-up of an analogue device, where the "component identifications and interconnections are positive and reliable" (ibid.). It is a formalising or coding at a higher level, and allows the analogue device to have specificity of action and to do useful work. This second-order digitality allows Haugeland to answer his initial question of whether "any analog device can be digitally simulated to any desired degree of precision" (ibid., 223) in a tentative affirmative, but only for devices which are analogue in a narrow sense. "But the universal digital simulability claim is often made in a more sweeping tone, as if it applied to *everything*" (ibid.).[33] Haugeland wonders whether there are "systems, perhaps 'analog' in some broader sense, which are not second-order digital, and not necessarily digitally simulable" (ibid.). He concludes there may well be, and has recourse to that ultimate complex system: the biological organism. Citing the case of the metabolic system of a rat, used as an analogue of the human metabolism to test effects of things such as clinical drugs, where some general relationships are known, and some local mechanisms are understood, still "these by no means provide a complete description, in terms of which responses to strange chemicals can confidently be predicted. The millions of delicate hormonal balances, catalytic reactions, surface effects, and immunological responses, all interdependent in a bio-chemical frenzy of staggering proportions… there is essentially no way to gain detailed,

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[32] These first two characteristics are key affordances that my modular synthesis piece *The Thing Breathed* (cf. chapter 5) explores.

[33] It is worth noting that since Haugeland's article was written in 1981, the sweeping, seemingly inexorable tide of digital simulability has come to encroach on more and more aspects of contemporary culture, but that the idea is nothing new.

quantitative control over such a mess – no hope of delineating a set of 'state-variables' which fully characterize it at a time" (ibid., 223-4). Such a multi-dimensional system, with dynamic and ongoing mutual determination and circularly causal effects, is not amenable to formal description; there is no fixed dimensional element that can be separated out for quantification or coding. In relation to the testing of drugs, Haugeland predicts that "there will *never* be a digital simulation of human physiology reliable enough to supplant (or even challenge) biological and clinical testing of new drugs" (ibid., 224). Perhaps the key thing about this second-order-non-digitality is that biological metabolisms are in constant flux, both internally and in relation to a changing environment. There is no way to fix the multiplicity of complex, nested, interconnected homeostatic processes in formal description or code, since the processes are always running ahead of and away from such fixity. This cybernetic principle will be met with repeatedly throughout this thesis, and even in the narrow perspective of the analogue device with 'second-order digitality' there are objections to the above, such as when concurrent processes intervene on the neat and clear demarcation of separable function in the temporal unfolding of a complex system; when feedback troubles the topology of an analogue computer (realised, for example, in my work in the form of modular synthesis, discussed in chapter 5) and obscures or complicates well-defined 'discrete and determinate' components; when the clear-cut distinction between an oscillator (outputting an *audio* signal at greater the 20Hz) and an LFO (outputting a *control* signal at lower than 20Hz) collapses as they are coupled into a closed loop, such that neither can be said to operate along their intended dimension and we can no longer say which is in control or even where that control exists in the relationship.

Analogue is not everything that is not digital

To bring the discussion into the (mixed, hybrid, analogue *and* digital) present, we can consider Jonathan Sterne's 2016 chapter 'Analog', that appears in Peters' edited *Digital Keywords* (Sterne, 2016).

Sterne alerts us to how use of the term analogue has changed in "cultural journalism, in humanistic writing, and in everyday talk" to take on "its most pervasive contemporary meaning", as "'not-digital' or 'separate from computers'" (ibid. 31). This meaning often carries with it a sense of old fashioned, outdated, not current. The detailed OED etymology that Sterne uses as case study has familiar sounding examples, such as 2005's "old-fashioned, analog game of Rock Paper Scissors", from Portland's *Oregonian* newspaper.[34] In modern parlance this game is doubly analogue because it is both not a computer game and it is old. But in Haugeland's terminology this game is a digital device, with its three fixed tokens, its immutable rule base, its equivalence across media. Sterne is clear that this "expanded notion of *the analog* as a condition" (ibid. 32) robs it of any useful specificity, since it expands to mean everything outside of the computer, that is, the entire world apart from 'the digital'. One of the problems with this is that it "effectively diminishes the variety of the world as it elevates conceptions of the digital" (ibid.). It works well for "digital boosterism", but "inflating 'the analog' to 'the world' limits the options we have for describing natural, cultural, and technological history to one kind of periodization (analog/digital, or maybe preanalog/analog/digital)" (ibid.). This periodising tendency, with its attendant succession logic, is examined in detail in chapter 6 in relation to music technology.

Sterne indicates how, over the 1970s and 80s, the terms analogue and digital start to move out from their more technical habitats – the languages of engineers, computer scientists, cyberneticians – and into popular discussion. As such they retain their distinction but analogue gets mapped in a more general way to technologies that are *not* digital – the traditional clockwork or quartz crystal timepiece, with its face and hands, starts to be called analogue to distinguish it from the increasingly prevalent digital watch (which is not called digital for its underlying timekeeping technology but for its display, which uses illuminated on/off segments to represent numbers). As people begin to discuss and use digital recording formats, then existing technologies of recording come to be known as analogue. To be clear, the terms analogue and digital were used in audio engineering circles long before this, but the act of making this type of distinction

[34] The OED entry is at http://www.oed.com/view/Entry/7029

in popular culture coincides with the arrival of mass market digital technologies riding the coat-tails of the much publicised and hyped computer revolution. "Sometime in the 1980s, the terms analog and analogue began to wildly proliferate, a trend that continued into the 1990s" (ibid. 31).

Alongside this analog = not-digital, Sterne notes a trend that develops in media theory, where analogue and digital processes are compared and analogue processes are found to be "closer to nature" (ibid. 39). To illustrate this perspective Sterne quotes Brian Massumi:

> the analog is *process*, self-referenced to its own variations. It resembles nothing outside itself… Sensation, always on arrival a transformative feeling of the outside, a feeling of thought, is the being of the analog. It is matter in analog mode. This is the analog in a sense close to the technical meaning, as a continuously variable impulse or momentum that can cross from one qualitatively different medium into another. Like electricity into sound waves. Or heat into pain. Or light waves into vision. Or vision into imagination. Or noise in the ear into music in the heart. Or *the outside coming in*. (Massumi, 2002, 135)

From the perspective of this thesis, this quote is interesting in that it promotes a view which is keen to counterbalance an overweening ubiquitous 'digital'. But Massumi's rhetoric is too one-sided, too eager to posit a straight opposition to millennial zeal around a digital revolution. One of the main problems with this passage is that it lumps too many different processes under the term analogue, and crucially omits *transduction*. Transduction can involve analogue or digital signals, processes, devices, but Massumi has renamed transduction "analog": the continuous variable "that can cross from one qualitatively different medium into another". I would argue that the *crossing* process is itself a transductive process. If what is crossing is continuously varying on either side of the transduction, then the crossing between media may be between analogue processes or signals. Whether the transduction *itself* is an analogue or digital process is a completely different matter. And the *continuity* relation is not, in itself, adequate as a definition of 'analogue'. Consider a canonic transductive process: operation of a microphone. The acoustic wave that initiates the sympathetic vibration in the microphone's diaphragm is continuous, as is the analogue electrical signal that the mic outputs. But the acoustic wave (a speaker's voice, for example) is not an analogue signal, it is an acoustic signal. To lump all of the sounding world under the rubric

'analogue' robs the term of any useful specificity. The most useful way to read this process is the commonsense one: acoustic signal, transduction, analogue signal. If all three of these processes is read as 'analogue' then analogue becomes meaningless. Massumi continues: "Like electricity into sound waves." This is what happens in loudspeakers, where an analogue electrical signal is *transduced* into an acoustic sound wave. And what of the pulse wave? Clearly, even in the continuous realm of analogue electronics this is a digital signal, and as well as *sounding* in the real world, without the need for digital to analogue conversion, it happily acts as that quintessential digital device, a switch. The problem with Massumi's rhetoric is that it tries to get analogue to do too much, to be too many things. Sterne is right that the equation of analogue with life puts too much burden on the term, asks too much of it. I would also argue that the issue of transduction is too important to bury it under another term. The concepts analogue and digital become both richer and more manageable if thought often in conjunction and inter-relation with transduction, particularly when dealing with audio, where transductions abound. This emphasises both their conjoined nature and their distinction, and suggests that we can make the cut across various dimensions, one illuminating one being transduction. The polarity, the binary opposition begins to blur, as the relationship takes on a dimensional orthogonality.

What of Sterne's own definition: "analog denotes a specific technical process, where one quality is used to represent another" (2016, 32)? This is in line with Pask's definition in *Micro Man*,[35] and with von Neumann's at the Macy conferences (Gerard, 2016, 181), and emphasises the analogy root of the term. Sterne takes issue with the equation of analogue with continuous, citing, as he does in an earlier paper (Sterne, 2006), the discrete nature of the ferric particles comprising the base of analogue tape. He takes exception to Stuart Brand's "Analog is continuous, digital is discrete (Brand 1987, 18)", stating: "Brand is in fact wrong about the continuous/discrete comparison — his example works with vinyl records or optical sound-on-film but not with sirens, magnetic tape, or player pianos" (Sterne, 2016, 37). There are a couple of issues here: first, Sterne's

[35] "An analog device… works by representing *directly* the quantities that are being manipulated" (Pask and Curran, 1982, 17).

definition fails to take account of the continuous nature of the "qualities" that are representing or being represented. In analogue computing, where this definition seems to be most apposite, it is precisely the *continuous* nature of the "specific technical process" that defines the process as analogue and distinguishes it from digital computing, with its discrete architecture. Similarly with an analogue signal it is the continuous oscillation of the wave (like radio) that differentiates it from the discrete pulses of the digital signal (like telegraphy). Second, not all analogue processes are representations, as Haugeland makes clear (though his comment is about digital devices it is just as relevant to analogue ones). Sterne won't allow the continuous nature of analogue tape,[36] but he will allow vinyl records to embody analogue processes; but what here is being represented? I would argue that the continuous undulation of the groove of the vinyl is analogue not because it represents a sound that occurred at a different time (capture), but because its continuously varying qualities mirror the continuously varying qualities of whatever was fed into the lathe at the time of cutting – it is an analogue of the continuously varying current that drives the cutting needle into continuous oscillations that are laid down onto the continuously rotating platter. What we are seeing here are chains of transductions that terminate in the groove of the record. Of course, at any point further back the chain there may be analogue or digital processes driving the next stage, as when a digital file is cut to vinyl in mastering, but this last stage of inscribing the disc is analogue. A new chain of transductions is initiated when the record is played back, the initial stage of which is also analogue. I would argue that vinyl records and other analogue recorded media are analogue because the final stage of transduction leads to a continuous linear trace or track, something laid down in real time. When this recording is played back the

[36] In relation to Sterne's objection to the continuous nature of analogue tape we can notice that he does allow a continuous magnetic field to be generated by the discrete ferric particles of the substrate (Sterne, 2006, 340), and I would make two points: (1) this is another example of the complementary nature of any supposed analogue or digital process, device, system; here continuous along one dimension and discrete across another; (2) again, it depends on scale and perspective: there may well be a discrete ground to tape's continuous magnetic field, at the molecular level, just as there is a continuous electrical field underlying the digital activity of a standard computer, but at the usual level of description, the recording of sound to tape – through the chains of transductions that lead to the tape head being driven by an electrical current to provide a continuously varying magnetic field, laid down onto the continuously moving tape – surely counts as an analogue process.

first stage of transduction (the movement of the needle transduced to an electrical analogue signal, the tape head converting the moving magnetic field into the same) will be from an analogue trace to an analogue signal. This definition has nothing to do with representation, but its use of continuous as essential is what Sterne dubs "wrong" (ibid., 37). My point is that this is the only way that the distinction makes sense in this context, but that it falls down as a definition of the distinction between analogue and digital computers, or watches. The terms analogue and digital exist to draw a distinction; that is their function. They distinguish different processes that have something in common, some axis of relationality. Thus it makes sense to talk about analogue or digital computation, analogue or digital signals, recordings, media, what have you. The distinction drawn *plus* the dimension of similarity is the way in to the definition; without this specificity the terms collapse under the weight of having to serve too many definitions at once. The corollary of this is that there cannot be any single, general, overarching definition of 'analogue' and 'digital' where those terms are divorced from any specificity of device, process, medium, what have you; where their hunger for substantives is not fed. The continuous-discrete distinction is not the only way to cut the analogue-digital distinction, but it is apposite in relation to certain processes, such as recording.

Ultimately, though, Sterne's plea is one with which this thesis is in wholehearted agreement:

> We should return some specificity to the analog as a particular technocultural sphere. That is to say that reality is just as analog as it is digital; and conversely, that it is just as not-digital as it is not-analog... The meanings we commonly attribute to the word analog did not even fully exist in the so-called analog era. Restoring some specificity to the term will help stimulate our technological imaginations... and free us from the burden of a history that was only recently invented. (ibid., 41-42)

Howard Pattee – continuous-discrete and other distinctions

Having explored, in some depth, philosophical and technical theories of the analogue-digital what have you from the beginning, middle and end of its 80 or so

year history, this next section takes us somewhat deeper into the drawing of distinctions as manifest in biology, physical theory and philosophy, which Howard Pattee has, at various points in a 50 year career working at the intersection of these domains, also applied to various theories of computation. The primary distinction Pattee elucidates is what he has termed the 'epistemic cut', which broadly equates to the distinction between knower and known, subject and object, and takes in the mind/body problem, though he is clear that he has "named all forms of separation between subject and object the *epistemic cut* to emphasize that it is *not* a Cartesian ontological cut" (Pattee, 2015, 463).[37] The epistemic cut implicates the observer in the act of drawing a distinction.

Related to the epistemic cut is the 'symbol-matter problem', which Pattee describes in relation to one of the fundamental principles of biology and of evolutionary theory, the interaction of genotype and phenotype, both in the physical expression of a species and in that species' evolution. Pattee posits the *genotype* as symbolic, discrete, descriptive code, and the *phenotype* as physical, continuous, dynamical interpretation of that code. Once again, we see the discrete-continuous distinction on opposite sides of a 'cut', but Pattee stresses the essential complementarity of the two sides in the frequent alternation between processes, and insists on their mutual co-implication rather than exclusion. He also notes the unbalanced nature of this reciprocity: "The amazing property of symbols is their ability to control the lawful behavior of matter, while the laws, on the other hand, do not exert control over the symbols or their coded references" (Pattee and Kull, 2009, 320). This refers to the fact that symbolic code, such as DNA, steers or directs forces and phenomena that can be described with the inexorable and deterministic (reversible) laws of physics, but that the creation of such code cannot be described in other that a statistical, irreversible manner.

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[37] There are similarities here with Barad's 'agential cut': "A specific intra-action (involving a specific material configuration of the 'apparatus of observation') enacts an *agential cut* (in contrast to the Cartesian cut – an inherent distinction – between subject and object) effecting a separation between 'subject' and 'object'" (Barad, 2003, 815). The 'knowing' inherent in Pattee's epistemic cut and the 'doing' inherent in Barad's agential cut both insist on a performative, contextual specificity to the drawing of distinctions that rejects the absolute dichotomy between subject and object in the Cartesian cut.

Pattee's lifelong ruminations on these matters are not raised here to say that the analogue-digital distinction is the same as his 'symbol-matter problem'. Rather that insights can be gained by making an analogy between a contextually specified digital-analogue distinction (i.e. with substantive such as 'recording') and the discrete-continuous distinction as Pattee draws it, with its associated code-implementation, description-expression, symbolic-physical, genotype-phenotype alternations. This is important in music production in the DAW studio, where the discrete code aspect also provides the recording medium, in the form of digital audio, leading to a situation where sound can be 'taken out of time', separable from a continuous milieu; in Pattee's terms audio has become time-independent, implementation-unspecific. Some of the implications from this are considered in detail in chapters 3 and 6.

There is one more caveat which it will be useful to consider here, concerning the apparent binary nature of all these distinctions. As Pattee states it:

> I think the 'symbol-matter problem' is maybe not the best name because it is a triadic relation. The symbol and matter must be connected by an interpreter (Peirce's 'system of interpretance'). Following the physicists' use of 'cut' to separate the measurement from what is measured, I have also called the necessary separation of symbol and referent the 'epistemic cut' which is also a triadic relation that must comprise the interpreter. (Pattee and Kull, 2009, 321)

This is an important caveat, because it precludes the drawing of these distinctions on absolute or objective terms of mutual exclusion: there is always an act of interpretation that binds as it cuts. This is also one of the ways this thesis treats analogue-digital: in order for the distinction to be made, there has to be an interpreter. There is no making the distinction without specifying various factors and ignoring various others. We call a computer digital because of its discrete symbolic control structure, or the constrained switching nature of the material transistors at the substrate level; we ignore the continuous electrical base. We call a recording analogue because of the continuous nature of the medium, or the way the fluctuations of a magnetic field are an analogue of the movements of an electrical transducer; we ignore the discrete ferric particles underlying the magnetic substrate. There is no absolute definition of the analogue-digital distinction that will hold in every case, or at every level. We make the cut along

lines that are useful to the conversation. We should acknowledge that how, where and why we make the cut thus carry an ethical responsibility. This is why this thesis argues against a digital present, a digital revolution and digital culture in general. These terms make a cut that posits a misplaced historicising – one of contestation and succession. Their use in contemporary conversations cloud those conversations with implicit sanctions, specifically, digital is new and analogue is old, both positions this thesis refuses.

Pattee's 1974 paper 'Discrete and Continuous Processes in Computers and Brains' stresses the need to look at the continuous and the discrete as *complementary* processes, both of which are essential for any full description of complex phenomena such as evolution or creative thinking. He questions the belief in the ontological primacy of the *switch,* and presents an argument based on biology, computer science, physics and philosophy.

Pattee notes the historical interrelation of theories of computation and theories of the brain, citing Turing, McCulloch and Pitts, and von Neumann. Historically, this interrelation has often been based on "the assumption, for better or for worse, that the nerve cell functions something like a discrete switch" (Pattee, 1974, 1). The model of the nerve cell, particularly the neuron, as communicating via all or nothing discrete pulses – the classic on or off switching of the digital signal – informed the highly influential McCulloch-Pitts artificial neuron,[38] as well as many other theories linking biological cognition with artificial computation. "We find many computer scientists who believe that, given enough switches, creating a truly intelligent 'thinking' computer is only a matter of programming these switches to behave in an intelligent way" (ibid.). A quick survey of how the contemporary popular press treats the issue of AI will confirm how deeply entrenched in the popular imagination this view has become. The reciprocal belief is in a deeper understanding of the brain through better computation. The main purpose of Pattee's paper is to ask some very serious philosophical questions informed by hard science about whether the concept of the discrete switch can

[38] McCulloch and Pitts (1945). See Boden (2008, 190) on the seminal importance of the McCulloch/Pitts neuron in the development of the digital computer.

provide a sufficient basis either for understanding human intelligence or for manifesting intelligence in computers. He agrees that the switch-neuron analogy can be useful, and where we can create models of cognitive functions which operate unconsciously, such as sensory and neuromuscular systems in interaction with the physical world, then a discrete symbolic description would be "very likely sufficient" (ibid.). A well-defined (i.e. formalised) model can happily exist as a discrete, symbol structure, but how are those models created in the first place, and how do they become well-defined? Pattee believes that "symbols are *created* in continuous dynamical time, and are only *preserved* in discrete, arbitrary structures" (ibid., 2). This preservation is held in memory (both cognitive, and also genetic, see below), which must compress the continuous, information rich, time-bound creative process into discrete symbolic code.[39] For Pattee the *creative* act of intelligence happens in a continuous dynamical milieu, and one of its primary acts is the creation of something – a concept, a model, a rule – that can be encoded as a discrete switching function.[40] To support this thesis Pattee mounts a sustained and detailed exploration of the switch, coming at it variously from philosophical, physical and biological angles. He contests the idea that at the physical level a switch is some kind of fundamental, objective element. Rather, it is itself a model: "a subjective interpretation made through some external system with which it interacts" (ibid., 3). The switch must be based on a physical dynamics, but the switching itself will necessarily be a suppression of those continuous internal dynamics and must be 'coded' by an outside agent; i.e. it is an *interpretation*. "This outside agent has, in effect, created its own internal model of the dynamics, and it is this model which we recognize as the switch. The discrete switch and its continuous dynamics therefore comprise *complementary* descriptions of a two-level relation which cannot be understood by either description alone" (ibid.).

From the hardware perspective of the computer we see this interpretation at work when the continuous dynamics of cross-coupled pairs of transistors are tightly constrained to 'flip-flop' around either side of a voltage threshold, interpreted as either 'low' or 'high', 0 or 1. This provides the functional base for the discrete

[39] See Pattee (1995) for more on compressibility of information.
[40] There are similarities here with Pask's thinking on the use of abduction, distinction and invention in the creation of new hypotheses (Pask, 1975a, 82-83).

symbolic operations that allow the digital computer its flexibility of programming, its substrate independence. The switching function must be independent of its underlying dynamics, or it would be called a bad switch.

Crucial to Pattee's argument is the incorporation of evolutionary theory to the discussion of intelligence: "the creative aspects of evolution are our best analogy to creative intelligence" (ibid., 5). The biological evolution of switches and discrete coding operations, primarily in the form of the genetic code, is something that life builds on top of the continuous dynamics of the physical world (from which it arose, some four billion years ago), as a way of sustaining its own survival.

Pattee holds that while it is true that a practical programmable computer depends on isolating the dynamics of the hardware from the symbolic level that the programmer interacts with, "the trouble with discrete automata models of intelligence is that theorists have mistaken the necessity of isolation for its sufficiency" (ibid., 8). The crucial dynamical and interpretive mode, in the mind of the programmer, is left out in this view, and computers show an extreme of separation between discrete symbolic operations (inside the computer) and continuous dynamical ones (outside the computer). Pattee compares this with living systems, where discrete switching modes are also kept separate from continuous dynamical ones, but not all lumped together. "Instead we find the discrete modes interspersed with dynamic modes at many levels" (ibid.). This continuous-discrete *alternation* is key to both cell physiology and evolution: "an essential requirement of evolution is the clear separation of the discrete genetic instruction from the phenotypic constructions" (ibid., 9). The phenotypic interpretation of the discrete genetic description is a physical, time-bound, continuous dynamical process. The example Pattee gives is of a cell's enzymes, the construction of which is directed by a discrete genetic code that "translates the sequence of DNA bases to a sequence of amino acids; but the linear discrete string of amino acids does not function as a selective catalyst until it folds up into a three dimensional active form. This folding is not programmed, and can only be described by continuous dynamical interactions of the entire string" (ibid.). The dynamical expression of this description is followed by the "sudden action of the catalytic event, which has all the characteristics of the discrete switch we have

been discussing" (ibid.). For Pattee this has profound significance for what he sees as related, 'higher' forms of human intelligence, such as creativity and learning:

> This complementary alternation and interaction of discrete symbolic modes with the continuous dynamical modes goes on at all levels of biological organization from the enzyme structure-function levels up through the sensory and neuromuscular structure-function levels. One is inclined to ask if this complementary discrete and continuous interaction is not also essential for the higher forms of intelligent behavior. (ibid.)

I would count any aesthetic practice as a higher form of intelligent behaviour, and thus Pattee's question is also one of the key questions of this thesis, and one I've been exploring through the deliberate removal of certain discrete elements from my aesthetic practice, pushing processes of creation and construction of music out of the discrete confines of the digital computer, in order to effect more frequent alternation and interaction between continuous and discrete. In contemporary technological musicking there is a trend, especially in DAW use and design, for more and more aspects of the production process to be "lumped into one box called the hardware where no continuous dynamical interactions or interpretation is allowed" (ibid., 8). My tape pop practice, which removes certain digital processes (specifically digital audio), is a 'de-lumping', pushing more of the processes of recording and production into continuous physical or analogue environments than DAWs encourage, but also allowing more frequent alternations between continuous and discrete processes. This is also why I have been exploring certain cybernetic principles through modular synthesis rather than digital programming languages such as SuperCollider, even though I have great respect both for the languages and their expert users. Again, this allows for more frequent alternation and interaction between the discrete and the continuous, the description and the expression, the score and the performance, the production and the recording, the rehearsal and the execution. These alternations are not isomorphic, they occupy different dimensions of description and temporality, but they all make a cut along similar lines: a coding and an implementation. It might seem odd to suggest that rehearsing is like coding, but in the sense that it prepares the performance of a program by laying down salient aspects of performance into memory there is certainly a coding (see also chapter 3 on programming the tape studio). This memory is now separated from the

dynamics of the performance itself, and serves as an active constraint on further rehearsal and performance.

Pattee is clear that if we want to build machines or automata that exhibit higher forms of intelligence such as creativity or learning, or that have the possibility of evolving in a manner analogous to the open-ended searching of natural selection, then we need to take seriously this "discrete-continuous interplay" (ibid., 10). Life, evolution, and, in Pattee's view, intelligence, exhibit this alternation and interaction at many levels, and across many timescales, and while the discrete mode can be modelled formally, the dynamical, continuous interpretation of that model "is not efficiently programmable" (ibid., 12). On the subject of how to design computers that display intelligence:

> Even the largest imaginable computer, if restricted only to the discrete switching mode of present day computers, can at best approximate only half a brain, and this will be the sequential, analytic half, not the generative, interpretive half… The trick will be to learn how to reintroduce a continuous dynamical mode into an artificial computer element at a simple enough level to be practical. (ibid., 14)

The maverick computers that Pask built throughout his life, from Musicolour, through the 'ear', to the many iterations of teaching and learning machines he concentrated on later, all exhibit this complementary alternation between discrete and continuous modes, and were all hybrid analogue-digital devices (Pask, 1979a, 227; 1976, 14). Chapter 3 discusses these in some detail and notes the intractable, and ultimately insoluble, problems Paul Pangaro had trying to instantiate Pask's hybrid THOUGHTSTICKER system in a wholly digital environment. A more recent example of the unplanned and spontaneous creation of continuous dynamical elements in a digital system through the action of a recursive evolutionary algorithm in an FPGA (Field Programmable Gate Array) is demonstrated in the work of Adrian Thompson at the University of Sussex in the 1990s (Thompson and Layzell, 1999). Thompson evolved a device, like Pask's 'ear', that discriminates between two frequencies. The FPGA is a programmable physical matrix of connected digital components (transistor gates) which is freely reconfigurable. Thompson used an evolutionary algorithm (EA) to successively hone in on the desired behaviour through iterative training of the array, rewarding desired behaviour following fitness evaluation. Initially the EA selects at random,

but promising behaviour in the FPGA means that that configuration will go into the next iteration, where it will be 'mated' with other promising candidates or be subject to random 'mutation'. It took some 4000 iterations, alternating between coded description of the EA and physical instantiation in the FPGA, to evolve a reliable frequency discriminator. The final evolved array exhibited several interesting properties: it had no master clock, unlike conventional digital systems (deliberately not incorporated by Thompson in order to allow evolution as free a reign as possible); some of its component transistors now acted in a continuous analogue manner, rather than the constrained, high/low flip-flop behaviour they were designed to operate with (in Pattee's terms they no longer function as well-defined switches); it was highly sensitive to temperature changes: it would only operate reliably at the lab temperature it had been trained at; some parts of the array appeared, through conventional analysis, to serve no clear function, yet if they were removed the whole thing would not function accurately; it had evolved complex internal feedback paths that further added to analytical occlusion; in fact, the whole thing was not amenable to conventional analysis, since any probing by measuring equipment would change its behaviour, and at the early stages Thompson admitted he had no idea how it worked at all. What is clear is that the evolved array was highly context dependent and implementation specific: if the same circuit was configured onto a different, though identically specified FPGA, its performance would be degraded. In other words, the device had moved, through the process of evolution, which alternated physical expression in the FPGA with coded description in the evolutionary algorithm, to just such a hybrid, continuous-discrete, "artificial computer element" that Pattee is interested in promoting.

Thompson's work, as well as Pask's 'ear', are discussed in Miller et al. (2014), which suggests that computing that makes use of continuous physical dynamics has much of significance to offer us. Work on 'in-materio' computing (ibid.) and reservoir computing (Caluwaerts et al., 2013) also suggests similarly exciting and profitable lines of enquiry. Still, the majority of work carried out today in computing, AI or otherwise, is carried out entirely within a discrete, coded environment (even if, as in the case of some deep learning systems, aspects of the code may be impenetrable to human cognisance). Late in his life Pask suggested

that physical assemblages based on the structural principle of tensegrity might be configured to operate as "elements of a potential concurrent computer" (Green, 2004, 1436), and it is interesting to note the connection here with reservoir computing.[41] Tensegrities form bounded structures that alternate discrete compression struts with continuous tension wires. I did initiate some work into tensegrity, culminating in an installation in the summer of 2016, but at present this work remains outside the scope of this thesis (cf. p.151).

The life (and evolution) of a song

To round off this chapter I'd like to briefly sketch how Pattee's ideas might be applied to an aesthetic entity. Aesthetic expression exhibits similar processes of alternation between description and construction. Consider the life of a song: the initial song-writing stage will involve multiple alternations (and interactions) between coded description and real-time expression. The writer may start at an instrument, playing until something catches, a chord sequence for example, which she then repeats, testing while committing to memory. This initial expression may be formalised in some way, such as writing down a chord sheet, or recording the ditty to a Dictaphone.[42] This initial structure then acts as a constraint on the next stage, which could be finding a melody for the chords, or finding a contrasting section. This searching stage will involve multiple attempts at expression, and may involve alternating periods of attention and inattention, which can lead to the oft noted moment of inspiration, when a melody, for example 'just popped into my head'. Pattee cites Einstein and Poincaré on the emergence of an idea or moment of inspiration and says that "descriptions of the creative process suggest a picture

[41] Thanks to Chris Kiefer for alerting me to reservoir computing, in connection with discussions about tensegrity. The two principles are brought together in Caluwaerts et al. (2013).

[42] For many, including me, this is essential. Like many others I have an internal catalogue of 'lost songs' (or parts of songs, more accurately), that I can remember playing, remember parts of the writing process, but cannot remember how to play. The memory is often associated directly with an occasion: sat at this piano; playing it to someone and saying 'it's a bit like Bacharach, don't you think?' An interesting reaction to this, that I have come across, is to deliberately not notate or record any part of the writing process, with the idea that what 'sticks' in the memory will be what is good.

of singularities arising in a dynamical sea of ideas" (Pattee, 1974, 10).[43] Singularities such as a melody, chosen from the sea of all possible melodies that might fit. In turn this melody will constrain possible lyrics. However it is reached, at some point the song will be deemed 'written'. At this mature stage of its life the song may be performed, or recorded, or notated, or find other forms of life. Note that neither the recording nor the notation is the expression, but the performance is. The recording needs to be played, that is, coupled to a material dynamics, to be expressed. In some cases the recorded version is 'definitive'. In many others, though, the recorded version expresses just one form of the song's existence. Audiences may hear it at different times (on the radio, at a gig) and construct memories that store aspects of the song: a melody, a hook, a lyric. Repeated listening informs this memory for an individual, but this building of description happens differently for different listeners. Some of those listeners may learn how to play the song, which will be a new and changed expression. Some listeners may base their performances on mis-transcription, a common enough phenomenon with online chord and lyric sites.[44] Although undoubtedly irritating, these inaccurate versions can legitimately be seen as mutations of the song's 'genotype'. These multiple new versions may go on to inform the evolution of the song in wider ways, as when a band record a cover, or make it their own in concert. Multiple pathways are possible for the evolution of a song, but each will follow this alternation of discrete, symbolic, time-independent *description*, and continuous, physical, real-time *expression*. Expression is where fitness is tested, as in an individual section making it into the song, or the song making it onto the radio. Description is where expression is plotted. Once the song is written, after the rather private developmental stage, the song itself exists both as a discrete code that informs multiple possibilities of expression, and as that expression. These

[43] Campbell (1960) and Penrose (1999) also cite Poincaré and Einstein in discussion of the emergence of novel or innovative ideas that we tend to call inspiration. There is also a link with Pask's use of 'abduction'.

[44] See for example the multiple online versions of the chords to 'Toxic' by Britney Spears, which almost universally get the complex harmonic structure of the song wildly wrong, often just duplicating others' mistakes. The only accurate online version I have found is this: https://www.hooktheory.com/theorytab/view/britney-spears/toxic. The transcription process itself will also move through alternating iterations of description-expression, where description formalises or codes whatever element is being analysed, and expression tests the code for fitness. Of course, 'accurate transcription' here points to my own position within a specifically Western framework of notational practices.

expressive possibilities are, to a large extent, now out of the hands of the songwriter. The song, as code, is a compression of all the possible expressions, into a stable, communicable store of implementation-independent information that that can be used to construct or express the song. That this code is not fixed or immutable is readily evidenced by following the multiple versions of any jazz standard; in other words, the song evolves. Chapter 6 zooms in on these processes in relation to the production of a recorded version of a song. From a slightly different angle, my modular synthesis piece *The Thing Breathed* is described at http://euterprise.com/index.php/music-research/modular-synthesis/the-thing-breathed/, which gives a prescription for the building of this piece, in implementation-independent form that delineates functional blocks. The patch diagram plus associated description is a plan for construction of the functional architecture, but gives no indication of *how* this is to be performed, since each performance is a remapping of zones of aesthetic significance laid down in the memory of the performer, through rehearsal and repeated performance. Expression depends on memory of previous expression (if the piece is to have any cogency in performance and not just be random search liable to bore both performer and audience), as well as essential symbolic constraints such as my own working patch notes that I had to refer to each time the piece was performed.

The analogue-digital what have you

Although there are occasions where one can say with reasonable accuracy whether some *thing* is analogue or digital, at the *systems* level, particularly when dealing with a complex system, it becomes increasingly a matter of interpretation. Perceptive analyses, like those of Pattee and Pask, acknowledge the hybridity and the complementary nature of analogue and digital elements in complex systems. For example, the process of a cutting needle inscribing a vinyl record is best described as analogue, with very little need to acknowledge digital processes. But the cutting needle is not in itself a system, and when we view it in the systemic context of a disc cutting machine there will be digital control elements (switches, relays, etc.) without which it could not operate effectively, and when we zoom out to the level of the mastering room where the record is cut, then it becomes clear

that we are considering a system with multiple analogue and digital elements and a richly interconnected nesting of continuous and discrete processes. It seems sensible to view activities such as vinyl cutting within a systemic context, rather than focussing too tightly on a single constituent process that is actually impossible to extricate from its wider technical environment. At the systems level disc cutting is a hybrid affair, with rich chains of transductions alternating discrete and continuous processes. It still makes practical sense to call the disc cutting machine an analogue device, since its function is the production of analogue vinyl records, but we shouldn't take the demarcation in any absolute way, rather as a matter of interpretation that fosters understanding.

That something is a matter of interpretation does not mean that it acquires less importance. On the contrary, the fact that we can choose how to draw a distinction gives us a responsibility. Terms like 'digital age' make it easy to overlook unforeseen effects on practice when recording becomes digital, by drawing on the assumption of progress and succession – if digital $i\omega$ the present, why record onto anything else? But this folds in too many contradictory practices, puts too much weight on the word digital, asks it to be too many things at once. Surely the multiplicity of practices that take the term digital vastly overweigh any possibility of monolithic meaning?

I am appealing for taking seriously the need for hybrid approaches that acknowledge the complementarity of the terms analogue and digital in actual technical (rather than linguistic) usage, and that refuse the "faith in formalism" that posits any single digital environment as sufficient for complex creative or aesthetic work. This is not to say that the programming of computers cannot be creative, for clearly it can and often is; rather that the process of programming is not digital, even if the result is. I am saying that I question the assumptions of strong AI, that a single digital environment might be sufficient for creative intelligence or learning. I am also suggesting that the trend of the DAW to swallow more and more physical or analogue elements of traditional studio engineering, including personnel and key creative processes, such as mixing, is problematic in all kinds of ways.

Analogue and digital always and only coexist is a polemical plea to consider carefully the implications of phrases like 'digital age', or 'analogue past', and to see the relationship between the two terms in a much more balanced way that acknowledges both their complementarity and the interpretation necessary in drawing the distinction.

CHAPTER 3: CONTEXT (3) – CYBERNETICS OF THE STUDIO

Chapter summary

The systems under examination are defined rigorously. An adumbration of Pask's cybernetics is explicitly linked to the domain of the recording studio. The composer/producer inhabiting and operating the studio is seen to be a participant observer who accumulates technical know-how through heuristic exploration. This embodied, tacit knowledge differs from that engendered by either surveying the literature of the domain, or by simulating in a different domain. The triadic relationship between composer/producer, technical environment, and music produced therein, form a cyclic, interdependent, dynamic stability that can be seen to evolve, manifesting the cybernetic property of self-organisation. The cybernetic system is seen to be an abstraction whose efficacy depends on isomorphism with real world systems (such as the recording studio). Pask's exploration of the relevance of cybernetics to architecture is expanded to include the recording studio. Studios, like buildings, demonstrate functionalism – how the system is meaningful only in terms of its use by human inhabitants – and mutualism – how the system both serves and regulates its users. A comparison of the ways the tape studio and the DAW studio regulate use is presented. Despite progress narratives that position the DAW as enhanced successor to the tape studio, issues such as the planned obsolescence of the computer industry, and the facile analogy between performance to tape and performance in the DAW studio, indicate that this move is not a straightforward progression. Pasks' Conversation Theory (CT) indicates that *processes* unfolding in a dynamic world of becoming explicate systems better than an emphasis on *things*. Concepts such as 'information' are not fixed things, rather they are contextually specified processes shared between interacting participants. Programming, in CT, is not a process unique to digital computers. When we compare the type of programming required for execution of the tape studio with that required in a DAW we find that they are of a different order. Appeals to isomorphism ignore essential complications. This can be seen most clearly in the area of studio *performance* (of the producer as well as the traditional performer): the tape studio marks a manifest commitment to all types of performance; the DAW tends to defer or abnegate such commitment. Pask was, in general, dismissive of ambitious claims made by computer scientists and AI proselytes – he did not believe all of reality could be modelled within a digital environment. The computers he built were hybrid, analogue-digital devices. He sought concurrent execution of multiple simultaneous processes, something the digital computer (and DAW) is not capable of, but the tape studio is. A discussion of self-organising systems presents a tentative formulation of the self-

> organising tape studio, the most interesting historical examples of which have the composer as producer, directly operating the studio system to produce their own music, forming a cyclic evolving unity: composer – studio – music produced. DAW studios present a serious obstacle to self-organisation in that one crucial element – the code the DAW is built upon – is not available to the user either to change or to aid the evolution of.

Introduction

This chapter maps a specifically Paskian cybernetics onto the domain of the recording studio. It attempts to do for studio recording what Pask did for architecture and other aesthetic endeavours and takes us necessarily somewhat deeper into Pask's Conversation Theory (CT). It is thus, I hope, complementary to Pickering's *Cybernetic Brain*, which gives Pask's work on CT "short shrift", as outside the remit of his book (Pickering, 2011, 330).

As noted below, the following is not a prescription for building a cybernetic studio. Rather it uses Pask's cybernetics as a provocative (and under-explored) way in to understanding the complex system that is the recording studio *in practice*, and as support for one of the central tenets of the thesis as a whole, the questioning of progress narratives that position the DAW (and other ubiquitous digital media) as successor to, and improvement on, analogue 'forebears'. It thus paves the way for (while also drawing on) the practice-based comparison between the 'tape studio' and the 'DAW studio' presented in chapter 6.

Definition and description of systems examined here

As with any cybernetic undertaking, we must demarcate and delineate, in as rigorous a way as possible, the systems under examination in this chapter and in chapter 6. Like any systemic demarcation there is an interpretive bias that needs to be acknowledged, and in practice there are many instances of hybridity that

complicate the somewhat arbitrary distinctions mapped below. Still, for purposes of comparison, the following will serve us well:

Recording studio

Environment for recording and/or production of recorded music.

This may be a physical or virtual environment. The and/or distinction becomes necessary with the incorporation of the DAW, since this environment affords a constructive approach, from prefabricated recorded music or internally synthesised sound, and may not involve recording at all.[45] It is important to note in all cases that at least one user/operator is part of this system.

Definition of key terms:

Recording – the laying down or storage of a reproducible transduced audio signal. Has to happen 'in time'.

Production – the construction of recorded music. May involve recording but not necessarily.

Recorded music – music laid down onto a medium that allows repeated reproduction, such that it can be listened to. Output of both the recording and the production process.

For the purpose of this thesis the wider recording studio system is divided into two distinct sub-systems:

Tape studio

Recording studio with a multitrack tape machine as main recording and production device.

- A fairly minimal system comprises multitrack tape machine, 2-track tape machine, mixing desk, loudspeakers, headphones, microphones, outboard equipment, instruments, personnel to operate the equipment, and a

[45] The irony of the system potentially not including half its own nomenclature is not lost, but commonly agreed upon terms have the utility of shared meaning, even if "your personal concept of something is not identical to my personal concept of what we (may choose to call) the same thing" (Pask, 1987, 18). The inclusion of the DAW in the 'recording studio' system is uncontroversial and necessary to what follows.

physical space to house all this, preferably partitioned into an area for performance (live room) and an area for engineering (control room).

- At minimum this system could be a song writer with a single 'boombox' (with built in microphone) with two cassette decks allowing sound on sound.
- Majority of work in studio revolves around performance, both musical and technical, and it would be highly unusual if a tape studio operated without recording of any kind.
- Recording happens onto a continuous medium.
- This type of studio was dominant from the mid 1950s until the mid 1990s.

DAW studio

Recording studio environment with DAW as main recording and/or production device.

- May include some or all of the elements of the tape studio, but multitrack tape will be replaced with DAW.[46]
- At minimum this system comprises computer, software, speakers or headphones, and user.
- Recording happens onto a discrete medium.
- Performance tends to play a less dominant role in production than in the tape studio, and there may be no recording involved at all.
- This type of studio has been dominant since the mid 2000s.

With these systemic demarcations in mind we can proceed to flesh out a Paskian cybernetics of the studio.

[46] Though multitrack tape may still be part of the system, as in the practice of recording to multitrack tape (for the sound) and dumping the multitrack into a DAW (for the editing). This scenario would still count as a DAW studio since the DAW would be the critical production environment.

Participant observer

> We must be participants – hypothesizing, scheming, testing, experimenting, prototyping, protecting our own interests – but still participants. (Pask, 1987, 9)

In the studio practice described in chapter 6 I inhabit many related roles: composer, performer, engineer, producer. In my reflection on this practice I cannot adopt a "view from nowhere" (see Varela et al. (1993, 27) for a brief discussion of Nagel's phrase); I cannot stand outside the practice, cannot be an external observer reporting in an unbiased manner. There is too much 'me' in the mediations, too much 'I' in the interactions therein. In this cybernetic exploration of the studio the observer is *necessarily* participant.[47] This causes some problems for a 'classical' scientific analysis of salient processes, procedures, constraints and affordances, where the observer is assumed to be external, outside the system: "Most scientific writing, even in behavioural science, takes it for granted that an observer can, in principle, act as a numinous and unbiassed entity called an external observer" (Pask, 1975a, 81). Pask notes that there are many advantages to this classical position, but there are also consequences that are not desirable, and situations where such a position is untenable.

Pask is clear that the central mental activity of the participant observer, when constructing hypotheses about the system in which they participate, must depart from the more usual induction and deduction of the external observer, and will be "a mix of abduction… of distinction, predication, or of cleaving out from a flux of events… and of rule invention to collect the distinguished fragments under the abduced principle" (ibid., 83). Abduction, for Pask, and following C.S. Peirce, is "the process of arriving at a new kind of rule or logical model" (Pask, 1961, 114), and is linked with both innovation and analogy construction (we will recall from chapter 1 that the construction and manipulation of analogies is central to Pask's cybernetic methodology). There are also similarities with Pattee's *creation* of formal, time-independent symbols as a dynamical, time-bound, medium-specific process (cf. p.46). The important point is that the creation of hypotheses about the

[47] Of course, the participant observer is not exclusive to second-order cybernetics. Anthropology, quantum physics, ethnography and other disciplines have all dealt with similar problems of observation and objectivity.

nature of a complex system requires that the participant observer employ their own embodied technical acumen *in conversation* with a dynamic technical environment. The "cleaving out from a flux" indicates that the system is dynamic, that it will not stand still, waiting around to be explained and understood by a numinous, external observer, unconnected to the system itself, and we are reminded of Ian Hacking's dictum: "Don't just peer: interfere" (Hacking, 1983, 189, cf. p.18), and Pickering's "nonmodern" performative ontology (cf. p.12).

The key thing for me, here, is that insights wrought from physical engagement with material practices are different to those that come either from surveying the literature of a domain (as explored in chapter 6 in relation to the studio) or from the attempt to simulate within a different domain (as is so common these days with computational approaches to a bewildering profusion of areas). In the cases under examination here, the observer is participant and uses various forms of expertise and embodied experience (e.g. tacit knowledge guiding heuristic exploration in search of underspecified goals, such as the successful production of a pop song) to help in the formation of hypotheses that may then be tested through further experiment and exploration. Conclusions drawn from this practical research are detailed in chapter 6, and are mainly centered on performance, commitment, gesture and contingency.

For Pask, the participant observer "engages in activities such as exploration, attention direction or non-trivial learning in which he exerts control over his environment and consequently changes the universe (either real or modelled) in which he operates" (Pask, 1975a, 87). In other words, in any situation where the system is dynamical and can be said to *evolve* as a result of interaction and goal directed exploration (even if goals are underspecified), as is the case in the systems under examination here. The tape studio, a system comprising both technical assemblage *and* engineer/composer/performer, changes through use, as its operator comes to know it through practice. As I come to know the environment through directed exploration, I change both its configuration (affordances) and my own knowledge of possibilities (constraints); this cyclic process leads to an ongoing dynamic stability which can be seen to evolve. In cybernetic terms, the system can be seen to manifest the property of *self-*

organisation (cf. p.77). We will come back to this important cybernetic concept, but for now the important thing to realise is that all elements of the self-organising system (including the participant observer) are in a contingent, interdependent, mutually accommodating relationship.

For our purposes, the cogency of CT stems from examining processes in interaction rather than positing pre-existing objects (including concepts) in a world 'out there'. It looks at conversation between individuals (or groups, or within an individual) from the point of view of meaning inherent in the conversation, as it is construed by individuals in a shared universe of discourse, and not from the perspective of pre-given realities (facts, concepts, knowledge). It doesn't attempt to establish factual truth, in any kind of universal, objective manner, rather it values agreement between participants, a shared bodying forth of 'knowing', a process of becoming.

Modelling and the cybernetic abstraction

> The [cybernetician's] object of study is a system, either constructed, or so abstracted from a physical assembly, that it exhibits interaction between the parts, whereby one controls another, unclouded by the physical character of the parts themselves. He manipulates and modifies his systems often using mathematical techniques, but, because in practical affairs cybernetics is most usefully applied to a very large system, he may also build mechanical artifacts to model them. (Pask, 1961, 15-16)

The 'cybernetic system' is an *abstraction*. Whether instantiated in mathematical model, physical assembly or a logic of distinctions, the cybernetic system itself is a winnowing out of principle, "abstracting a controllable system from the flux of a real world" (ibid., 15). In the cybernetic abstraction 'particulars' are irrelevant; these might be energetic considerations, physical specifics, disciplinary constraints. The cybernetic method looks for commonalities of principle that bridge disciplinary boundaries, physical instantiations, modalities. It is the 'abstracting out' of these principles that is the key cybernetic procedure. In answer to the criticism that cybernetics is trivial, since "anything whatever can be defined as a system", Pask holds that "an answer can be given, provided we do not confuse

the strict identity of principle between the workings of several assemblies, which the cybernetician tries to embody in his abstract system, with mere facile analogy" (ibid.). Cybernetic models do not attempt to *imitate* the workings of a particular device, assembly or system, and at this stage it may be useful to note, in contrast to the "popular, but deeply misguided, conflation of cybernetics with computers" (Cariani, 2017, 123), that the DAW is *not* a cybernetic model of a tape studio. Of course, it imitates all kinds of features, but it cannot be said to form a cybernetic abstraction of the tape studio, since the principles of operation, and the behaviours it manifests and engenders in its users, are of a completely different order. The oft-made, but mistaken facile analogy would state that the tape studio and the DAW are isomorphic because the end result, a piece of recorded music, is the same; alternatively, they are analogous since both are about the capturing of a performance. From the perspective of this thesis both statements are outright denied. In the first case the analogue recording, in its relatively fixed and 'definitive' status, has a very different character and universe of operations to the fluid, mutable and endlessly recombinant digital 'recording'. In the second, as we will see, both the status and nature of performance change between tape studio and DAW, in terms of the centrality of the procedure to the domain, and in the commitment given to it in practice.

In discussing "brain models" that fail to reach the level of the cybernetic abstraction (and thus are not terribly useful in elucidating the workings of an actual brain) Pask notes that it "is easy to cite brain models which are merely imitations; most well-behaved robots, most of the tidy automata that imitate a naughts and crosses player… There are not so many cybernetic models to choose from, but one of them, made by Ashby and called the Homeostat, admirably illustrates the distinction" (Pask, 1961, 17). He insists that "if the device *is* a cybernetic model, then it is almost certainly a *very* poor imitation" (ibid., 16), and that it "is only at the level intended in the cybernetic abstraction that the self-regulation in a homeostat is *identical* with the self-regulation in a brain, and with reference to this feature the homeostat *is a* cybernetic model of all brains" (ibid., 17). The homeostat does not imitate the workings of a brain; rather it instantiates, physically, the abstracted out principle of self-regulation. The homeostat cannot be regarded as a cybernetic model until there is an acknowledgement of the

abstracted out principle – in this case self-regulation – that is isomorphic between the model and what it is modeling. The homeostat by itself is not a cybernetic system. The homeostat plus the analogy with brain function through the similarity of self-regulation is the cybernetic system.

We will keep these ideas of the cybernetic model and the cybernetic system in mind as we proceed in our investigation and exploration of the tape studio and in our comparison with the DAW studio, which will proceed via a comparison with an article Pask wrote in 1969 about architecture.

The relevance of 'The Architectural Relevance of Cybernetics' to the cybernetics of the studio

In elucidating a cybernetics of the recording studio, it will be useful to look at the ways in which cybernetics drew parallels with other practices and disciplines that operate across a spectrum of aesthetic and client-based professional activities. In 1969 Pask wrote an article on 'The Architectural Relevance of Cybernetics', and although architecture and the recording studio are clearly different domains, there is much here that is apposite to the studio dynamic, explored from a cybernetic perspective. Pask had little to say about music, but he did comment at length on *design*, which is a principle of operation and practice that applies at all kinds of levels to the studio: physical design of the studio including layout and ergonomic constraints as well as systemic technical schema; design of the song (composition); design of the recorded expression of the song (production); design of a software emulation of a piece of hardware, and so on.

In 1969 the use of computers in architecture was still somewhat novel, and Pask notes that "Computer assisted design is a 'cybernetic' method and there are several instances of its application to architecture" (Pask, 1969, 494). Why does Pask scare quote his own discipline? Because by this point, to him, the link between cybernetics and computers had descended to the level of stereotypy, devoid of cogency; it had become "facile analogy". The filial relationship between the interdisciplinary domain and the general or special purpose computational artifact

had been acknowledged since their co-implicative births in the 1940s.[48] Cybernetics used the computer as model builder, as exemplar, as systemic functional component, and in a host of other ways. The computer used cybernetics as theory builder, as consultant, as meta-language, and in a host of other ways.

The point for Pask was that linking cybernetics and computer aided design was trivial, as much as it was obvious: "If we leave the matter at this level, then architects dive into a cybernetic bag of tricks and draw out those which seem to be appropriate" (ibid.). What he's much more interested in are the deeper connections and correspondences that operate at the level of the cybernetic abstraction: "cybernetics and architecture really enjoy a much more intimate relationship; they share a common philosophy of architecture in the sense that Stafford Beer has shown it to be the philosophy of operational research" (ibid.).

Many musicians are used to diving into the "cybernetic bag of tricks": any time they explore feedback; or when they develop a meta-language to talk about technical systems, as modular synth users do; or draw on homeostasis, autopoiesis, self-regulation or cellular automata in the making of sound installations. Despite this, the common ancestry in cybernetics is seldom acknowledged.[49] Studio operation is still an under explored area from a scholarly or critical perspective; it surely could benefit from a philosophy of "operational research", and might then share in the kinship Pask proposes for cybernetics and architecture.

Pask adumbrates architectural *functionalism* and *mutualism*. A building may be functional (as opposed to decorative), but "the concept of functionalism can be usefully refined in an humanistic direction. The functions, after all, are performed *for* human beings or human societies. It follows that a building cannot be viewed simply in isolation. It is only meaningful as a human environment. It perpetually

[48] This is, of course, a somewhat arbitrary dating. We could go back further and link Babbage's Analytical Engine (1837) with Ampère's coining of 'cybernétique' (1834), or further still and note the coincidence of J. H. Müller's theoretical anticipation (1786) of Babbage's Difference Engine with the Watt Governor (1788). ("Analytical Engine," 2017, "Centrifugal governor," 2017, "Cybernetics," 2017, "Difference engine," 2017).
[49] This is not to say that cybernetics invented or originated all these concepts, rather cybernetics is the first place where their conjoined significance is manifested and explored.

interacts with its inhabitants, on the one hand serving them and on the other hand controlling their behaviour… I shall dub this notion architectural 'mutualism' meaning mutualism between structures and men or societies" (ibid.). As a studio user, denizen and designer this quotation is strongly redolent of studio operation, and could be rewritten thus:

> The functions of the studio are performed *for* human users. It follows that a studio cannot be viewed simply in isolation. It is only meaningful as a human environment. It perpetually interacts with its inhabitants, on the one hand serving them and on the other hand controlling their behaviour… I shall dub this notion studio 'mutualism' meaning mutualism between the studio environment and its users.[50]

This co-implication of human user/inhabitant and technical ensemble/environment is central to Pask's cybernetics,[51] where it is given a much more rigorous and reciprocal treatment than either the usual user-centered approach that posits technical milieu or built environment as serving inhabitants, or the other equally one-sided pole that considers design of device or environment in their own terms, without due regard for individual difference of user or evolving patterns of use.

> One consequence of functionalism and mutualism… is that architects are required to design *∂ynamic* rather than *ıtatic* entities. Clearly, the human part of the system is dynamic. But it is equally true (though less obvious) that the structural part must be imaged as continually regulating its human inhabitants. (ibid.)

Clearly, this is equally applicable to the studio environment, and this issue of the dynamics of the studio environment *regulating* the uses to which it can be put, and the ways in which it is used, is central to this comparison between tape studio and DAW. No studio environment is *neutral* with regard to its usage, and although we

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[50] An interesting and relevant historical example of such studio mutualism can be seen in the 'at hand' ergonomics of the Studio 54 setup at Pierre Schaeffer's GRM from the late 1960s. "The Studio 54 desk allowed a single user to perform tasks which, according to conventionally hierarchised (and fiercely union-defended) roles, previously involved a composer, desk technician, and studio manager. The new work situation, which evokes the future garage or bedroom type digital creative industries practitioner as much as the traditional lone genius composer, was a revolutionary social aspect of the GRM's general organology: artist-technicians could explore sounds independently, in freely looped listening, learning, and shaping activity" (Norman, 2018). See also Teruggi (2007, 219).

[51] See also Varela et al. (1993, 197): "The opposition between inner and outer causal factors is replaced by a coimplicative relation, since organism and medium mutually specify each other."

might suspect (because this is how it is invariably presented in the literature) that the DAW is *more neutral*, since it is seen to have greater affordance and less constraint, my practical exploration of both shows this not to be so. Regulation (control, homeostasis, feedback) is a central concern of cybernetics, and a cybernetic theory of the studio must put regulation at its heart. Not just tuning, maintenance and control of the technical milieu, but equally how the technical environment regulates use. This 'less obvious' type of regulation often eludes attention precisely because of the assumptions we make about technologies serving our needs; but every time we struggle with a function in a DAW, every time we check out a YouTube 'how to' tutorial, or use the default reverb preset on a plugin, we are being constrained, conditioned and regulated by the very technology we assume we control. The constraints of the tape studio are better known and more commonly acknowledged, since they are written into the very history of the DAW, a history that is presented as emancipatory and progressive, by dint of how the DAW 'saves' us from those constraints: increased editing functionality, cheaper infrastructure, greater numbers of tracks, etc. Of course, the tape studio also conditions us in ways which tend to remain below the radar until we actually start to use it.

Broadening his remit from individual building to larger ensembles, such as cities, Pask notes that the city, also, cannot be viewed as a neutral container of society: "On the contrary, its structure acts as symbolic control programme on a par with the ritual constraints which are known to regulate the behaviour of various tribes and which render this behaviour homeostatic rather than divergent. Hence the architect is responsible for building conventions and shaping the development of traditions" (ibid., 494-5).

Here, via a typical cross-disciplinary analogy, we are back to regulation and we should note the concomitant ethical imperative: the responsibility of the architect. Pask notes that this comment "simply elevates the idea that a building controls its inhabitants to a higher level of organization" (ibid., 495). In terms of the studio we can compare this to ecologies of studio production in a culture, and note the ways in which the dominant trends in studio design and use, which these days are often outside of an actual physical studio ('bedroom' production), condition, constrain

and regulate the music that is made in them; we see how these nested and interconnected sets of studio practice evident in a culture mutually inform and determine each other. We, the studio designers and users, have a responsibility towards the establishment of conventions and the ongoing development of traditions. My own studio work, presented here, in its small and local way (but not disconnected from the wider studio ecology), is attempting to ask questions about these conventions and developing traditions, by examining in critical detail, through practice, the regulatory and controlling natures of both the dominant DAW paradigm and its supposed forebear, the tape studio.

Developing his theme Pask notes that "systems, notably cities, grow and develop and, in general evolve" (ibid.). Architectural designs should therefore have "rules for evolution built into them" (ibid.), and the responsible architect must be concerned with evolutionary properties and shouldn't just sit back and watch change happen. One of the more unfortunate, and in no way necessary, aspects of the 'evolution' of the DAW, is the planned obsolescence inherited from an avaricious computer industry.[52] Although many engineers initially welcomed the adoption of DAW systems that meant they weren't having to spend portions of each session calibrating tape machines, they soon came to realise they would have to spend significant amounts of time on calibration and infrastructure development as hardware and software go through their supposedly essential 'upgrade' cycles. One example of this enforced evolution comes from Apple, who have deliberately precluded any kind of backwards compatibility between their DAW Logic X and its precursor, Logic 9: its purchase is more or less forced on professional studio operators as a new crop of clients come to sessions with Logic X projects that cannot be opened in Logic 9. There are alternatives, of course, to any DAW – engineers could, for example, switch to an open source system running on a Linux OS. But, as Apple are well aware, inertia and the prospect of significant financial and time commitments necessary for adopting a new system, put many engineers off such a change. There are a lot of grumbling engineers and producers out there who don't have control of, or even a say in, the evolution of the very systems they rely on. We are, in the studio environment, a very long way

[52] On planned obsolescence see Rodgers (2015, 12), Sterne (2007), Nelson (1987, 53).

from Pask's responsible architect, building adaptive systems that respond to and evolve alongside patterns of use that change between individuals and through time.

Conversation Theory

> Conversation Theory grew up as a body of hypotheses, often focused upon social, psychological, or educational matters. These matters arose out of my work of 35 odd years, dealing with a curious mixture of mechanical, philosophical and human issues - such as for example (mostly deviant) computing systems, social support systems (including that most important social support called entertainment), human machine systems for training, maintaining vigilance or workload, learning concepts and skills, police organisation, selling, innovation and decision making, by people or by small teams. It became clear, chiefly in the context of educational support, that the existing paradigms were insufficient. Hence, Conversation Theory grew up, albeit slowly. (Pask, 1987, 18)

To further flesh out the cybernetics of the studio it will be necessary to delve a little deeper into Conversation Theory. CT is a *process* philosophy, a cybernetics of *becoming*. It does not attempt to explicate a given world 'out there' but to explore the processes by which meaning is created and shared by participants through the interaction Pask dubbed 'conversation'. Concepts, language, even information are all seen as processes unfolding in a dynamic world of becoming. Rather than being some fixed, measurable entity, information is defined "in, roughly, the sense of Carl Adam Petri, to mean the becoming of a coupling between otherwise independent systems, or, equisignificantly, the becoming of a synchronization between hitherto asynchronous systems" (Pask, 1992b, no pagination). Information is not something that can be separated out from the context of its communication; it is an active, dynamic process involved in coupling between autonomous systems; it is a becoming of *coherence*. Concepts are similarly seen as processual, contextual and dynamic: "Concepts (alias, skills, usually intellectual skills), are processes, resulting from the execution of a cluster of procedures where, in turn, a procedure is defined as the compilation of a program in a computing medium; either a human brain, or an artifact" (Pask, 1979a, 2). Throughout his writing Pask is extremely careful in his use of language, which is itself a process at the heart of CT. He rigorously defines his concepts throughout, not to 'say the last word' on a concept such as 'concept', but to allow the theory to

be formal, consistent and general, and to allow it to be 'ported out' into media other than academic writing, such as a modelling facility, a (mostly deviant) computing system, or a dynamical formal logic. Before exploring Pask's "computing medium" in detail, we can draw on his notion of programming in relation to tape studio and DAW. Programming can be seen to be a broader concept than the image of (digital) computer coding, but does, nevertheless, have a strict definition in CT.

Programming

One of the problems with much of the literature of the DAW is that it positions the DAW as *isomorphic* to the tape studio (cf. chapter 6), whereas their relationship is one of weak analogy, at best. They *are* both control systems. They *may* operate in similar fashions. But as control systems they operate with very different sets of *programming* languages. This point is lost when the DAW is presented as the evolution of the tape studio, and when they are assumed to speak the same language: "We appropriate terms [in DAW use] from the analog recording world all the time, because the concepts remain the same, and they work" (Leider, 2004, 168). Unlike John Stroud, who argued for an acceptable workability of terms and approximations, with the devil in the details situated somewhere between (cf. p.32), Leider's comment presents a problematic obfuscation. The programming language of the tape studio is generalist and transferable in scope, even as it is personal in application: familiar with the general set of elements such as multitrack tape machine, analogue mixing desk, cables and patchbays for connecting elements together in standard ways, the tape studio operator can easily move to another tape studio environment and rapidly apply general principles to the novel environment so as to quickly allow their individual predilections to come to bear on the environment. The programming language of the DAW is substrate specific, and, in the case of a 'closed' platform like Logic, intractable, a black box: inputs and outputs may be parametrically interacted with, but the box is closed; the operator cannot get 'under the hood', and the coupled system of DAW and user cannot evolve in the way that an open programming language such as Pure Data, coupled to a community of users, can and does. The

Logic user might happily take their skills to another Logic enabled environment, but if the novel studio is based around Pro-Tools, Cubase, Reaper, or any other DAW then they will struggle, and it will take them much longer to get 'up to speed' than in the comparable tape environment. To make matters more complicated, the DAW *appears* to offer exactly the programming opportunities of the tape studio, and thus masks and diverts attention away from the fact that the type of programming is of a very different order.

Programming the tape studio for execution involves a gamut of embodied, gestural, performative routines where know-how is embodied, setup and calibration is gestural, and execution is performed as a coherent, concurrent synchronisation of otherwise separate and distinct autonomous or semi-autonomous elements. This type of programming is antithetical to that which leads to the serial execution of the digital computer, since all elements form a cyclic organization: they mutually inform, determine and interact with each other, and this co-determination is concurrent and continuous. In the tape studio, the execution of a program starts *when you hit record* (cf. p.23), or when some other technical performance, such as tape editing, occurs. The key point is that the execution of the program is performative – it *has* to happen in real time, as a synchronous coupling of autonomous elements. At its simplest a performance is recorded to tape. Layers of programming complexity can be added to this simple base, as is the case in the performances of the mixes discussed in chapter 6,[53] or the laying down in one pass of a rhythm track with multiple interacting elements, common (and less common) clocks, and a performer to play *with* the whole thing.[54] To be sure, the execution can be *rehearsed,* and often this process is necessary and lengthy, but the process is only made concrete when the 'red light' is on. The case of tape editing is slightly different, but there is the same gestural-embodied-performative cyclic organisation, and the same 'moment of truth' when you cut into the tape or splice cuts together.[55]

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[53] See, for example: http://euterprise.com/index.php/music-research/euterprise-ep/letter-game/#Final_mix

[54] See, for example: http://euterprise.com/index.php/music-research/euterprise-ep/substantive-hungry-trouser-word/#Rhythm_tracks

[55] Similar programming affordances and constraints can be seen in the mixing desk. Once you understand the basic operating principles of an analogue mixing desk (through

For Pask, program execution *has* to happen within a particular computing medium. He makes a sharp distinction between program, processor and procedure: a program, such as an algorithm or standard computer program, is a series of syntactically valid instructions. A processor, such as a brain or other computing medium, is the environment in which a program is compiled and interpreted. A procedure is the execution of the program within a specified computing medium. "It is nonsense to say *'Ex (Prog),'* meaning 'Execute *Prog'* [program] with no processor implied, as it would be in standard computer science; one *can* say *Ex (ProcA)* [execute procedure A]" (Pask, 1979a, 231).

The important point is that *programs* are context dependent: they have to be executed within a specific (computing) medium. The program 'record' might appear as a simple algorithm, e.g. setup microphone on performer, connect output of mic to preamp, connect output of preamp to recording device, set gain, press record. This program has the benefit of generality, and looks as if 'tape machine' and 'DAW' will fit equally well into the 'recording device' of the algorithm. But once we start *executing* the program, by actually recording to tape, or to the DAW, then we start to see that the *procedures* are different. At the level of the general algorithm above there certainly seems to be an isomorphism between tape and DAW, but the problem is that we humans, as performers, operate at a much more complex and messy level than this simplistic rendering affords. Specifically, we carry with us histories of practice and foreknowledge of procedures: as indicated in chapter 6, the experienced performer has a different attitude towards performance in the DAW realm, as they are aware of the affordances of post-recording editing and manipulation, and as a result, perform in a different way to the more highly charged, 'moment of truth' nature of tape recording. Further, the different emphases given to sensory modalities, differences of gestural interaction and ergonomics, and their own knowledge of post-recording manipulation

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practice), you will find it fast and unproblematic to adapt to a 'new' (to you) analogue desk. The situation with digital desks is the exact opposite: if you learn how to operate one it gives you *no* general principles that you can apply to other desks (digital or analogue), and the learning required in any new situation will be complex: you may very well get very good at learning how to read, and operate from, manuals in a fast and efficient manner, but the only sense in which it makes any sense to say 'I understand the operating principles of digital desks' is to say 'and that is that they are all different, and all require significant cognitive investment to make then functional'.

possibilities, mean that the engineer is also operating in a different manner and exhibiting different behaviours with execution of 'recording' in the tape or DAW environments.

Exploring these differences in a practical way, with conviction and commitment to what is produced, soon leads one to realise that the *procedures* 'recording to tape' and 'recording to DAW' are categorically *not* isomorphic. Skeuomorphic emulation in the DAW occludes this distinction, and does so in collusion with the progress narratives written into the history of succession, increased affordance and 'democratisation' of the DAW.

Computing media

At points, the language of CT sounds like computer programming language: procedures are formed from programs, compiled and interpreted for execution within a computing medium. But Pask's computing medium is not the same as 'computer', as generally understood. The human brain is the computing medium he is most interested in, but all kinds of other systems can be usefully employed, such as a modelling facility, or a well-specified formal logic such as Pask's Lp,[56] operating as a shared interface through which conversation can happen: "An interpretation (semantic) of Lp expressions consists, invariably, of many 'universes', a priori independent, but rendered locally dependent by analogy; each 'universe' consisting in a process (not, for example, a set). Refer to this collection of universes, non-commitally, as the 'computing-medium', whether they are brain, or machines, or organisations in society (urban structure, information search, communication, transportation)" (Pask, 1979a, 1-2). The generality of cybernetics is once more in evidence. Throughout his life Pask built physical devices, artifacts and systems to explicate and exemplify the principles he was exploring, all of which were, in the general sense here, computers. But Pask's computers are not what we have come to understand by the term; Pask tended to avoid the standard

[56] Lp is the "proto-language" or "proto-logic" underlying CT; a dynamical, formal logic used to compute CT processes. See Pask (1979a).

digital, Turing/von Neumann architecture, since he found it unable to compute the kinds of *concurrent* processes he was interested in: "*Process* in general is *not* Turing representable" (Pask, 1979c, 486). The serial, one step at a time, paradigm was found to be inadequate as a way of modelling the kinds of dynamic, kinetic cognitive processes underlying the interaction of actors through conversation. Pask built Musicolour, "the first coherence-based hybrid control computer" (Pask and Curran, 1982, 144); he built the 'ear', an "electrochemical device… having emergent sensory capabilities" (Cariani, 1993, 1); and throughout the 60s and 70s he built "epistemological laboratories" such as CASTE and THOUGHTSTICKER, which physically modelled CT in an interaction interface of analogue/hybrid form, which allowed both instantiation of theory and an environment in which to observe interaction and glean "hard" data (Pask, 1979a). All of these devices had digital elements, but never was the entire system housed within a single digital environment. Paul Pangaro, who built a digital "simulation" of CT in the form of the software implementation of THOUGHTSTICKER makes the point clearly:

> 'THOUGHTSTICKER' indicates a user interface written in software and connected to a software embodiment of Lp structures and processes ('Lp software'), within the constraints of present digital technology, which constraints are very great compared to the intention behind the formal protolanguage itself ('Lp'). Multi-process, concurrent, conflict-ridden as well as conflict-free computation are a few of the gross omissions inherent in any present-day THOUGHTSTICKER. Even the proposals of modern AI for non-von Neumann, many-processor digital hardware is not capable of the proper processing that is required for Lp. (Pangaro, 1987, no pagination)

This version of THOUGHTSTICKER was an attempt to make portable and marketable the rather large hybrid device Pask and associates had built at Systems Research, Pask's laboratory and base. Pask's paper 'An essay on the kinetics of language' gives considerable detail:

> The main focus is THOUGHTSTICKER as an epistemological laboratory (EL) in which plans, expositions, etc., are spelled out as Lp expressions which are checked for legality and represented in a canonical graphic form, the entailment mesh (EM). The EM is an interface between participants (authors, planners, curriculum designers or learners). Emphasis on computers is <u>only</u> a convenience, and may be misleading, (a) because Lp and CT are machine independent (epistemological, social, psychological) constructions of considerable generality;

> (b) because, insofar as generality is achieved, Lp and CT provide a theory of general intellectual operations, whether carried out by human beings or not, which surely includes intelligent other-than-human, or other-than biological systems. However, the computing machines able to embody such operations are concurrent with many independent loci of control (their implementations resemble a group, or population, of devices), and have little in common with serial processors, or the operations usually associated with 'artificial intelligence'. (Pask, 1979a, 1)

Here the computing medium is seen as a population of devices, or more accurately, a population of processes executed in a population of interpreting media, including at least one brain, interacting concurrently only in local synchronisation (i.e. with no master clock). The systems Pask put together as epistemological laboratories were created to explore the areas mentioned (epistemological, social, psychological), but there is no reason why such a system shouldn't be designed along similar lines, to explore studio recording. Once one starts to look at it like this it appears very much as if such a system already exists: the tape studio. It is a population of autonomous processes, coming together in only local synchronisation, steered by one of more human actor. Of course, the DAW studio *can* operate in a similar manner, primarily if the focus of attention is outside of the DAW itself, e.g. on performance, on outboard hardware and instruments, on people. But if the majority of time is spent operating 'in the box' then the system ceases to be concurrent and moves further away from the rich spectrum of interactive possibilities that CT proposed and that its instantiations in hardware went some way to realising in human-machine interaction.

There are, of course, large differences between THOUGHTSTICKER and the recording studio, the most important being not the difference in domain, rather that THOUGHTSTICKER existed not just to embody the principles of CT, but also to collect verifiable, empirical results about hypotheses of learning and cognition. Pask built physical devices and assemblages to test out philosophical and cybernetic ideas in empirical situations, where evidence could be gathered and analysis of evidence could feed back into the ongoing scientific quest of disproving hypotheses (in the sense of Popper). Presented as a scientific research operation Pask could continue to secure funding to enable the whole thing to keep generating itself, self-organising, if you will. The recording studio is obviously a very different environment, concerned as it is with the production of recorded

music. Evidence gathered from this aesthetic environment is necessarily of a different type to the hard scientific data Pask sought to generate. Still, we need not be strict in our demarcation of science and art. Pask himself saw them as complementary and coexistent: "For myself, I have never been able to see the distinct cultures of C.P. Snow as divergent; art and science, psychology and aesthetics seem, to me, part of much the same enterprise and they coexist together" (Pask, 1992b, no pagination). His own work happily crossed over into theatre, installation art, music/computer interaction, architecture, and so on. I'm certainly not proposing that had Pask been asked to help design a recording studio he would have accepted that which already existed; I don't think he would have seen the tape studio as an EL in the manner of THOUGHTSTICKER. He would most certainly have wanted to design a system that learnt about its operator as she learnt about the system. I can though, be certain that Pask would *not* have designed the entire system within the architecture of a digital computer, had the stipulation been that the system embody CT's "theory of general intellectual operations".

The cybernetics of the studio, outlined here, is not a prescription for how to build a cybernetic studio. The plan for that *ώ* being hatched, as this thesis grows itself, and as the business of cybernetics proceeds through exploration, model building and research, all both practical and theoretical. At present, the tape studio system I've built (and am part of) *ώ* cybernetic, to a degree, in that it *ώ* self-organising and it *does* evolve. It does not, as yet, reach the conditions Pask outlines as the conclusion to 'The Architectural Relevance of Cybernetics'. A truly cybernetic studio would be responsive and adaptive, it would learn about the wishes, needs, predilections of its user(s), it would act as an "odd mixture of catalyst, crutch, memory and arbiter" (Pask, 1969, 496). Pask says that these "are the dispositions a designer should bring to bear upon his work (when he professionally plays the part of a controller) and these are the qualities he should embed in the systems (control systems) which he designs" (ibid.).

At present it is me, as user and controller, who is embodying these qualities in the tape studio, which is why it is 'less cybernetic' than the Paskian cybernetic studio. Note though, that these dispositions are not ones one associates with 'command

and control', of imperious will, of forcing technology to do our bidding; they are of coaxing, of going with the grain, of steering: in short, they are cybernetic. I catalyse reactions, I prop up ailing tech, I keep copious notes of my interactions to serve as memory and to aid evolution, and I continually arbitrate what will, ultimately, 'make the cut'.

The cybernetic studio would take some of these duties off my hands, or take the place *of* my hands, where gesture could be delegated to the system. But the objection is quickly raised: surely that *is* what is happening when the DAW automates processes? The point is that the DAW *in no way* learns about the individual operator, in no way does it adapt itself to the predilections and quirks of the user; quite the reverse in fact: it regulates and encourages all kinds of behavior based on assumptions that may well have nothing at all to do with the way the operator wants to use the system. Goals are too tightly specified to allow for any kind of open ended evolution (cf. p.14). The user has little agency in steering the evolution of the system that includes herself. Conversation is stifled because the machine *doesn't listen.*[57]

Neither, at present, does my tape studio, but it is no further away from this condition than the DAW. 'Growing cybernetic ears' is about trying to find ways to encourage the system to listen, so as to be a more compelling conversational partner. The greater incorporation of modular synthesis into the studio environment is one possibility; greater engagement with sensors linked to a programming language like SuperCollider is another. As it stands, the DAW voids serious contention.

The self-organising studio

> [A]ny system with a behavior that becomes more ordered (according to some vague criterion or other) is called a 'self-organizing system.' (Pask, 1964, 110)

[57] "To listen is to join in with what has been said. To speak is not to join in: to speak maybe to offer, but it is not to join in. To listen is to respond: to speak is not. Speaking, we have no influence and no companionable listeners unless others chose to listen. It is the listeners who collaborate" (Glanville, 2001b).

> Naturally occurring networks, of interest because they have a self-organizing character, are, for example, a marsh, a colony of micro-organisms, a research team, and a man. (Pask, 1959 232)

> Self-organizing systems was perhaps the most visionary subfield of cybernetics research. (Cariani, 2017, 121)

Both the tape studio and the DAW studio are self-organising systems, both in terms of one individual in their own studio, and in terms of wider cultures of practice. One key difference, which presents a major obstacle to self-organisation, is that in the DAW one significant part of the system, the computational architecture, the code, is inaccessible to the system itself. The DAW system can, and does, evolve, but the nature and order of this evolution is very different to that of the tape studio where every element is available to be tinkered with, improved, personalised, misused, pushed into unfamiliar shapes, and the wider tape studio culture has been witness to the vast spectrum of activities of 'making fit' in individuals' and small groups' own studios. Making fit could mean reading the manual for everything, doing everything by the book, going to class; excellent results have been achieved like this. It might mean jerry rigging your tape machine to put an extra record head before the playback head to enable sound on sound recording (Bell et al., 2015, 2): Les Paul's particular creative misuse comes right at the start of the ongoing evolution of the tape studio and is rightly dubbed 'revolutionary'. Making fit could mean burying your master tape in the garden for three weeks to mature, after you urinated and blew ganja smoke onto it;[58] although it is unclear exactly how this misuse affected the subsequent release, it is an example of the kind of extreme tinkering the tape studio will happily accommodate.

[58] See Veal (2007, 160–162). Lee Perry's studio Black Ark is certainly a high point in the history of the self-organising tape studio. Perry himself seems to have seen the whole system as a dynamical, symbiotic entity: "I see the studio must be like a living thing, a life itself. The machine must be live and intelligent. Then I put my mind into the machine and the machine perform reality. Invisible thought waves - you put them into the machine by sending them through the controls and the knobs or you jack it into the jack panel. The jack panel is the brain itself, so you got to patch up the brain and make the brain a living man, that the brain can take what you sending into it and live" (quoted in Toop (1995, 113)).

How does this figure in the evolution of these domains? In the case of the DAW the vast majority of agents employing the system do not have direct access to, and therefore cannot directly influence, the evolution of the system. The access they do have is with each other, as communities of users who are in turn accessed by the programmers: they help each other out on forums indicating gripes and glitches to be thought about or ironed out by programmers who also frequent these sites. In some cases the evolution of the software seems primarily to be driven by financial consideration (e.g. Logic X's lack of backwards compatibility); this frustrates and alienates users. In any case, the channel is narrow and possible injection of variety is low. Evolution is forced, from a certain direction, is not open, and is certainly not self-adapting.[59]

The situation in the tape studio is one where every element is open to manipulation *by the users*. This internal process of change is not the same as the evolution of, say the multitrack tape machine, from 2 to 4 to 24 tracks, or of the analogue mixer, from home made to SSL; rather it is one of the whole tape studio environment *and* the user/operator *and* the music which is made there, all in mutual, ongoing, evolving interaction. This evolution is particularly marked where the studio is operated primarily by a single artist/producer, such as the case with Lee Perry, and artists such as Prince, Kate Bush, and Laurie Anderson,[60] who eschewed the standard practice of a record label paying for professional studio time, and built studios for themselves where they produced their own music. The self-organising character of such studio spaces – where artist, studio environment and music produced are all in ongoing interdependent and mutually accommodating development – manifested in groundbreaking albums such as Prince's *Lovesexy* or Kate Bush's *Hounds of Love*, albums that *sound* like no other album, and where one can hear how songwriting and production are in an intimate and co-specifying relationship. A self-organising studio such as this has "evolved its own relevance criteria" (1993, 4), as Cariani said of Pask's chemical computer, the 'ear' (cf. p.101).

[59] There are open coding environments for development of plugins, but these still have to be hosted within the DAW which is not open.
[60] Both Prince and Kate Bush also employed additional in-house engineers, though Prince could certainly operate the studio on his own (Helmreich and McMurray, 2017, 138).

Clearly any studio that releases music into the world is self-organising to a degree. The most interesting case of the self-organising tape studio, as I see it here, is where the composer is the primary studio denizen, where they have their hands (literally) on the means of production, and where this 'at handness' requires an accumulation of embodied know-how for adequate expression of the song in development. This embodied musical cognition directly feeds into the sound of the song in production, or even into the initial conception of the song (writing in the studio); in many cases the evolving technological infrastructure becomes substance of the composition itself. To be clear, it is this triadic relationship – composer/producer, studio, music produced – that forms the system which can be seen to become progressively more ordered, to recapitulate Pask's definition of the self-organising system at the top of this section.

That it is the composer steering a studio that has shaped itself around their own musicking is the important distinction between this and the traditional client-studio model. Practical, embodied know-how, coupled to the need to service the song adequately, directly feeds into the sound of the song, through an ongoing, increasingly ordered evolution. The artist's performative interaction with the studio technology often leads to the technology itself being subject and substance of the act of composition. We hear this with Kate Bush's use of the Fairlight on *The Hounds of Love* and other albums produced in her own studio; with Prince's use of tape speed manipulation of his multi-tracked backing vocals on albums produced at Paisley Park; with Lee Perry's live dub mixing at Black Ark. Truly exceptional studio self-organisation occurs when execution of a repertoire of techniques by the composer/producer becomes virtuosic. The exemplary image of operation of the self-organising tape studio is Lee Perry performing a dub mix, with hands dancing around knobs and controls, with devices patched into the "living brain" of the jack panel, multiple tape reels rolling, feedback flying around, producer and music-in-production locked into local and very meaningful synchronisation with each other and with the "living man" of the studio (see footnote 58, above).

At the beginning of the era of the tape studio, many of the original *designers* of the infrastructure of multitrack tape machine, mixing desk and outboard processors

were the operators of the environment: Les Paul modifying his Ampex to allow sound on sound recording; Bill Putnam designing and building some of the earliest studio mixing desks; Tom Dowd evolving the ergonomics of Putnam's invention by exchanging rotary pots for linear faders, eight of which could be operated simultaneously, one per finger, so that when mixing he could "play the faders like you could play a piano" (Bell et al., 2015, 2-3). They built these systems to service their own needs, and because existing, off the shelf solutions were not available. It soon became clear, though, that these inventions had very general and widespread applicability, and their utility and functionality was built upon and improved by a new generation of specialist inventor designers such as Rupert Neve, who, though not a studio engineer, has spent his entire career in conversational (technical, interpersonal, innovative) interaction with studio environments.

Even if users are given access to the code, as in some open source DAWs,[61] there is still the fundamental problem that this part of the system, the code, is only indirectly related to what they are trying to achieve: the production of music. They have to learn another, more or less completely unrelated language, in order to get at what the DAW actually does. This is not the case with actual music programming languages, such as SuperCollider or Pure Data. It could be argued that modifying the operation of a tape machine by altering its electronics is also far removed from the production of music, but most tape studio users have some knowledge of electronics, even if only at the level of intuitive 'grasp' or 'feel', since much of what they do in the studio deals with sound in its electronic form; many can wield a soldering iron and some are able to make their way through a schematic in a service manual. There are many examples of studio engineers with a bent for electronics moving from 'modding' their own gear, to building outboard devices and studio tools from kit form electronics, to designing their own equipment and eventually forming their own 'boutique' company to market the designs. Of course, modifying or designing electronics, at the device level, is only one way that the tape studio system is open to *internal* development: other types of

[61] Such as Ardour, https://ardour.org/.

creative misuse or novel reconfiguration litter the history of pop music production.[62]

By the time DAW designers come along an entire professionalised domain, the recording studio, has been established, and so it is impossible, not to say unfair, to try to make one to one comparisons between original studio equipment and infrastructure designers and DAW designers. However, it is still moot to note that DAW design deals with code, with issues of Human Computer Interaction (HCI), with the specificity of digital audio, and these wider, computer-based priorities get 'ported over' to, instantiated within, a skeumorphic virtual studio environment. DAW design is accomplished by teams of people, most of whom are coders, not studio engineers. There is plentiful dialogue between designers and users, often within the design team itself, but the fact remains that the design and maintenance of these tools is primarily locked in to a specific platform or coding environment which is not, even in the case of open source platforms, accessible to the majority of users, either to maintain or to develop.

As befitting a chapter highlighting the thought of one individual, I give the last word to Pask, who treats a similar point in 'Conversation and Support'. Although here he is discussing the design of "collective support systems", we note that these can be read as "including that most important social support called entertainment" (Pask, 1987, 18), and can perhaps suggest the liberty of replacing 'model' with 'DAW':

> It would surely be no worse, and it might be much better, if potential users were allowed not only to interact with the model designers during the formulation and revision of the model, but also if their own creativity was mustered in support of the model maintaining operation. Without such interaction a 'loss of distinction' will occur between the users (or equivalently, a variety reduction). This may be derived from the fact that the distinct problem formulations and domains of potential users are not participantly observed (rather than numinously, or externally observed). Clients will be treated as uniform, and alienated if they will not wear the uniform. The design forces the users to be less distinct than they wish. (ibid., 10)

[62] Such as, for example, slapback echo on Elvis' voice; the Beatles' use of 'automatic double tracking'; Kraftwerk's extensive array of modified instruments and bespoke devices; Lee Perry's dub mixes; Trevor Horn pushing the limits of nascent digital studio tech.

CHAPTER 4: PRACTICE (1) – TAPE MUSIC COMPOSITION AND TAPE INSTALLATION

Chapter summary

The first of three chapters dealing with the practice, covering the earliest practical work completed in the area of tape music composition and installation. The chapter explores a contemporary tape music practice, utilising historical electronic music techniques prevalent from the 1950s through to 70s. The importance of practical investigation is stressed, leading to different insights from surveying the literature or simulating in another domain. A successful tape music practice requires embodied know-how, and can be linked to notions of craftsmanship, centred on the nexus of hand-ear-mind. Even expert listening in the tape studio is accompanied by a gestural interaction with the reel to reel. The process is extremely time consuming, and affords much time for reflection. Personal experience in areas deemed isomorphic, such as sampling, presents an obstacle to learning the technique, since procedures expected to be straightforward, such as synchronisation, turn out to be extremely difficult in practice. Three insights follow: (1) Digital techniques that present themselves as isomorphic to tape techniques do not map backwards in a straightforward manner. (2) Such difficulties may help in explaining the eschewal of rhythmic synchronisation in canonical examples from the historical practice (such as a great deal of *musique concrète*). (3) Historical music practices that do foreground such techniques (much of the output of the Radiophonic Workshop) do so only by demonstrating an extraordinary virtuosity: an embodied, performative mastery that one is only able to truly acknowledge through attempting similar things oneself. These embodied techniques form an essential part of the aesthetic of the music produced. The physical interface and embodied interactions of the tape music studio directly affect the types of musical cognition that takes place there. Tape music installations broadened the remit of the tape studio, placing the materiality of tape directly into the physical presence of installation participants. Playful interactions with these environments were enthusiastic and emergent.

Introduction

The next three chapters deal with the practice that has been developed through this PhD. It proceeds chronologically, taking in my early work in this chapter,

modular synthesis performance in the next, and my practical explorations of the tape studio in chapter 6.

Let us first step back, for a while, to a time before I knew cybernetics. When I started this research, in 2013, I had but a vague idea of what cybernetics actually is. This thesis grew cybernetic ears as a result of my discovery of how the concerns and practices of Pask's cybernetics resonated so deeply with my own artistic concerns, but before we get there we can consider the earliest practice-based research I conducted into tape music composition and installation. Concerns at the heart of this work revolve around craftsmanship, tacit knowledge, gesture, risk, commitment and playfulness. The discussion also explores how practice-based research is able to generate insights that are often not available from either a purely theoretical, textual standpoint, or through simulation, especially when exploring practices and techniques generally considered historical, such as tape music.

The practice lies in two areas, both analogue tape-based. (1) Experimental work in tape music composition, [63] which, although it did not result in any finished pieces, was a thorough exploration that did lead to significant insights, and laid important groundwork for the tape pop productions discussed in chapter 6. (2) Two tape music installations, *The Long Loop* and *What are the Benefits of Sound?*[64]

Tape music and craftsmanship

This chapter refers to 'tape music', meaning the clutch of practices, prevalent from the 1950s to 70s, that used analogue tape for the recording, manipulation and assembling of what came to be termed 'electronic music'. This includes, but is not limited to, *musique concrète, Elektronische Musik* and the early work of the Radiophonic Workshop. A contemporary tape music practice can be seen to be part of a 'turn to the physical' (material, corporeal), manifesting in many social,

[63] Documented at http://euterprise.com/index.php/music-research/musique-concrete/
[64] Documented at http://euterprise.com/index.php/music-research/sound-installations/

cultural and academic areas in recent years. A few, specifically musical examples will give a flavor: the upturn in sales of vinyl records; the profusion of DIY cassette labels; live coding in electronic music performance; extended instrument design; use of gestural controllers and other sensors in live performance; motion tracking as a source of control. Analogue tape is still being manufactured (despite a short hiatus in the 2000s), indicating a healthy demand. High quality tape machines are easy to come by on eBay and elsewhere, and are, in the main, cheap, compared to the time of their manufacture. And since starting this PhD, German company Ballfinger have manufactured the first new series of reel to reel machines to go on sale for many years.[65] Two of my reel to reels came from the college where I taught at the time; the technician who gave them to me was only too happy to see them pressed into further use – they would have been scrapped otherwise. The conditions are good for setting up a contemporary tape music studio, which is what I have done. I stress the importance of a *practical* investigation of these techniques and technologies, rather than a theoretical or simulated one. My experience here has shown that this embodied practice cannot truly be understood either by surveying the literature (textual, from both practitioner and commentator, and recorded) or by employing digital simulations. You have to do it to know it.

After familiarising myself with basic tape music techniques (cutting, splicing, looping, reversing, tape speed manipulation, etc.), my first committed compositional tape music work used the sounds that resulted from the installation *What are the Benefits of Sound?* (discussed below). These sounds were originally on endless cassette, and were noisy and low quality, but not without sonic interest. The first task I set myself was to create a looping melody from portions of these, so the cassettes were recorded to reel to reel tape and I searched for any single notes that could form the basis of a melody. Promising candidates were extracted from the tape. Once the individual sounds are extracted they are spliced into short loops using leader tape (silent, non-magnetic tape). The looped sounds can then be recorded multiple times onto a second reel: a manual copying process that has to be approached carefully, since each re-recording of a sound introduces

[65] See http://www.ballfinger.de/tape-recorder-m-063-h5

increased tape noise: sound can appear more and more 'buried' with each iteration of re-recording. I spent a great deal of time experimenting with EQ and compression in order to make usable notes. Eventually there were enough different notes to form a complete melody. Careful calculation of physical length is required, translating beats per minute into tape length. One of the unanticipated challenges was that every separate piece of tape had to be meticulously labeled (on the tape itself), since there is no indication on the tape of what sound is on there. Once a small piece of tape has been extracted, if it has not been labelled, the only way to tell what is on there is to splice it into a loop, which takes time. One learns to be highly organised in the tape studio, with administrative duties equally important to more 'creative' activities.[66]

Every aspect of the technique requires physical, learnt skill, which includes an embodied practice of listening, necessary in order to remove fragments of sound from longer sections. To find the sound you want to extract you have to manually 'rock' the tape reels back and forth, listening the whole while.[67] As you get closer to the beginning or end of the sound you are trying to extract, you have to move the reels more and more slowly, which lowers the pitch of what you are hearing, making it more and more difficult to tell what you are actually listening to. This is not too difficult to pick up where there are strong, individual transients, such as the drums you see me edit in the second video of footnote 67, but in dense musical material it is a tricky procedure. This difficulty is made more acute by the fact that you can only tell if you have got it right by physically cutting the extract out, putting it into a loop, and then playing back the loop. At this point, if you've got the edit wrong, you have to splice the whole thing back together and try again. This is an extremely time consuming process, but the risk involved sharpens the commitment one makes not just to the cut, but to the initial act of listening. This heightened, embodied cognitive activity – centered on the nexus of hand, ear and musical mind – leads to a very deep engagement with sounds that are inextricable from their material instantiation. I would argue that differing cognitive

[66] See section 'Melody' at http://euterprise.com/index.php/music-research/musique-concrete/

[67] See me do this at https://www.youtube.com/watch?time_continue=27&v=lihzmlxPJcw and https://www.youtube.com/watch?time_continue=33&v=_VJxasayZSs

engagements with sound and materiality lead to very different sounding musics, and we shouldn't necessarily expect a practice dealing with the materiality of the digital computer to be either isomorphic to a tape music practice, or to reveal anything much about the 'precursor' techniques (such as happens when, for example, an undergraduate course exploring historical electronic music techniques uses sampling in the DAW to teach *musique concrète*).

Of course the other thing is that if one gets the cut slightly wrong (i.e. there is a touch of a previous note in the loop) then one might well accept this (due to how long it would take to correct) and this unintended aberration then goes on to be part of whatever one is making. Thus contingency and deviations from a plan can form an important part of the sound of the music being produced. This encourages one to adopt *underspecified goals* as the most productive approach (cf. p.14).

Tape music is now an unusual or marginal practice. Although the historical practice has been well documented, with many useful sources that explicate the processes,[68] I found when I started to explore it that there was much I had to learn for myself, and there was much that was missing from the manuals. Learning by experiment, somewhat in the dark, I found that many things that seemed self-evident from the literature turned out to be anything but in practice. Here I will highlight one aspect I found difficult: synchronisation. Getting two separate sounds on two separate pieces of tape to play at the same time is a challenging procedure, particularly if you want two rhythmic sections to *stay* in time, and the literature has very little of use to say on the subject. I have, in my heuristic fumbling, found some ways to facilitate this,[69] but the medium's synchronic intransigence led to three important insights. First, as a digital audio and sampling-literate composer, I expected this to be easy: if you have two pieces of audio in a DAW it is extremely easy to drag one of them to another track so that it vertically aligns with the other sound. In fact you don't even need to listen to do this. If you want two rhythmic sections to stay in time there are a host of procedures that facilitate this relatively easily, mostly utilising digital audio's

[68] E.g. Keane (1981); Strange (1972).
[69] See me do this at https://www.youtube.com/watch?v=nZhvPUR-V_I. Discussed below.

temporal plasticity ('take-out-of-timeness' as it is dubbed in this thesis) and the presence of an external grid (timeline, masterclock) in a sequencer or DAW. It became clear that many of the techniques of electronic music that I took for granted in the digital realm would not easily map back onto the analogue techniques, even though these digital techniques appear to owe their ancestry to analogue forebears. Second, that the difficulty of rhythmic synchronisation in tape music directly fed in to the sound of the music produced in the era of classic tape music composition: examples from *musique concrète* and *Elektronische Musik* show very little in the way of rhythmic synchronisation between different layers of sound. They tend to display a succession of (very interesting) sounds, and where there is layering this tends not to be metrical organised, or have a clear sense of pulse. It is important to remember the cultural context of electronic music in the 1950s and 60s: the lack of regular pulse was part of the aesthetic of serialism that dominated the post-war musical avant-garde. But it does seems likely that this difficulty of rhythmic synchronisation was an important motivation in practitioners avoiding it. The major exception to this is the work of the Radiophonic Workshop, whose work on the creation of theme tunes and other pieces of incidental music for radio and TV dramas and documentaries displayed a masterful command of these very difficult synchronisation techniques. Examples like the one seen in 'The Delian Mode' (Blake, 2009, at *4'42"*) where Delia Derbyshire manually synchronises three rhythmic tape loops, display an extraordinary level of virtuosity (though like many virtuosi she makes it look easy). It was only through trying to do similar things myself that I was able to truly acknowledge this virtuosity, and to truly understand that the mastery of the machine displayed here is a performance. That led to my third insight: there is no making tape music without this embodied, performative acumen.

One reason for highlighting the virtuosity of Delia Derbyshire and others is that even in the 60s, at the height of tape music's dominance of electronic music, there were many who were looking for alternatives to the often painstaking labour and hard-learned, embodied technique that it required. It *is* slow, and it does require many, many hours of practice to attain any kind of *control* over technique. Peter Zinovieff, a pioneering British electronic composer, whose company EMS provided the Radiophonic Workshop with their first synthesiser in the early 70s,

said in a documentary from 2006: "it was very early on that I realised: cutting tape was a *hopeless* procedure" (Bate, 2006). Zinovieff was an early advocate of computer music: "digital computers were already used for *process control* in factories; that was exactly what we wanted – we wanted to process control for different sounds" (ibid.). In other words, he was looking for a situation where the production of electronic music did not depend on physical, embodied procedures that relied on skill that had to be acquired through practice; rather the control of sound was seen as a process that could be automated, leaving the composer free to concentrate on composition (rather than production). This indicates a rather traditional view of the act of composition as generation of a score that then has to be assembled (whether through electronic means or through instrumental performance). From this perspective it matters little whether the subsequent construction is (meticulously, slowly) assembled by hand or (quickly, efficiently) generated automatically by computer; the assumption is that the result will be the same, since the accurate construction of what the score specifies is the important thing. This though, is a completely different methodology of electronic music production to that practiced by Delia Derbyshire (or Pierre Henry and other *musique concrète* practitioners), which sees the direct generation and manipulation of *sound* as the key compositional activity, and this cannot be separated either from the medium of construction, or the embodied, skilled techniques necessary for such generation.[70] Derbyshire, Henry and others did use notation, scores and plans of various kinds, but a large amount of their work involved a kind of exploratory wayfaring, coupled to an extraordinary repertoire of technique, in pursuit of sounds, gestures, motifs, rhythms that were then assembled, via further embodied tape techniques, into the finished piece. This is more akin to craftsmanship – dealing directly with *this* piece of wood, with its particular knots, grain, and physical specificity – than the "process control" that Zinoviev was after, with its implications of automata serving the will of the composer: a hierarchical separation of composition and production, along the traditional lines of performers

[70] There is an interesting irony here, since the general public tended to hear such productions by the Radiophonic Workshop as *disembodied*, eerie, otherworldly. As the Workshop's Dick Mills recalled: "most of the stuff that we produced in the early days [was]… tormented, to say the least. There [were] many letters in Radio Times about 'what is this fearful noise coming out to accompany these so-called arty programs. It sounds like skeletons on a corrugated iron roof!'" (Blake, 2009, 7'14")

servicing a score. In cybernetic terms, Derbyshire and the *musique concrète* school followed underspecified goals, whereas Zinoviev's approach demanded tightly specified goal-states.

There is no doubt that tape music techniques are physically and cognitively demanding, but I found I had a deep engagement with the physical manipulation of tape and razor blade; I enjoyed the slow, methodical pace of the practice, and I appreciated the time for reflection that slowness affords; I was fascinated by the practice as a form of craftsmanship, as a way of structuring and ordering the thinking/making mind in its embodied engagement with physical tools and the environment. Richard Sennett's philosophical treatment of craftsmanship highlights the "slow craft time" that "enables the work of reflection and imagination" (Sennett, 2008, 295). One of the things that interests me working in this medium is *its own* resistance to *my own* assumptions about what can be done with sound: thinking through a particular problem (like how to extract from a noisy sound something that can form the basis of a melody) with my sampling-literate mind, I find (after much time and effort) that the answer I initially imagined does not work (I subject the noisy sound to processes which, involving repeated re-recording, serve to *increase* the noise) and I have to go back to the drawing board, armed with knowledge more appropriate to the constraints of the medium. This forces me towards a more exploratory, improvisational form of creative thinking around the problem; this halting, circuitous wayfaring leads to many failures, that have to be accepted as part of the process, but there is a great sense of satisfaction when you get it right. As Sennett notes: "The difficult and the incomplete should be positive events in our understanding; they should stimulate us as simulation and facile manipulation of complete objects cannot" (ibid., 44). The reward is something rich and unexpected. A personal high water mark in my tape music composition work was the example of getting two quite long, meticulously constructed loops to play in sync for an extended period.[71] Though not at the level of virtuosity that Derbyshire displayed, this certainly gave me a much greater appreciation of her performative acumen: a combination of extremely precise craft skill – cutting the loops to exact lengths such that they can

[71] See https://www.youtube.com/watch?v=nZhvPUR-V_I

synchronise – and masterful performance skills in setting them going. Both types of skill manifest an embodied cognition, involving tacit knowledge, gesture, risk and commitment, and we shall look into these issues a little more deeply in the next section.

Embodied cognition in the tape music studio

Klemmer, Hartmann and Takayama (2006), working within the broad tradition of human computer interaction (HCI), go to great lengths to establish the importance of the physical interface and environment in cognitive work, and how "theories and research of *embodied* cognition regard bodily activity as being essential to understanding human cognition" (ibid., 141).[72] Their discussion centers on interactive design, but much of what they say has rich relevance to the practice of tape music. They point up the importance of *tacit knowledge*, of embodied know-how. They highlight *gesture*: "systems that constrain gestural abilities (e.g. having your hands stuck on a keyboard) are likely to hinder the user's thinking and communication" (ibid.). And they draw our attention to *risk* and *commitment*: "Digital artifacts often do not exhibit commitment to actions; in fact, being able to index at random into the past of our creation through undo/redo and versioning may be the single most important characteristic that separates the digital from physical interactions" (ibid., 145). In the tape studio the embedding and subsequent embodying of tacit knowledge is essential before any serious work can be done; indeed this know-how is an essential prerequisite to any serious *thinking* about what can be done. Likewise, the gestural – the performative playing out of embodied routines such as tape editing – is essential to the crafting of sound, where the engagement with the materiality of tape is inseparable from ongoing musical cognition. Similarly, the inherently risky nature of working with

[72] Klemmer et al. build on work by Kirsh and Maglio, whose concept of "epistemic action" highlights how certain actions taken by an agent in the world operate not to advance a specific plan ("pragmatic action") but to effect a changed view in the agent's mind on what is possible in the world, unearthing "valuable information that is currently unavailable, hard to detect, or hard to compute" (Kirsh and Maglio, 1994, 515). This is also relevant to the loose, exploratory, physical work with tape discussed here.

tape teaches one to pay close attention to the consequences of action: errors of measuring, cutting, labeling can all lead to extremely time consuming corrective work. One of the axioms of carpentry 'measure twice, cut once' applies equally well to tape work, and this inevitably leads to a commitment to the actions one takes (cf. chapter 6 on commitment in the tape studio).

To return to one of the key themes of this thesis – questioning the progress narratives that underpin the assumption that digital technologies will succeed analogue or physical 'forebears' – it will be useful to note one further comment from Klemmer et al.:

> The project of technology is the creation of increasingly malleable materials, and computation is perhaps the most malleable created so far. Given the techno-utopian ideology of computer science, it can seem heretical to suggest that one should undertake a project other than replacing the physical world. Clearly, the digital world can provide advantages. To temper that, we argue that *because there is so much benefit in the physical world,* we should take care before unreflectively replacing it. (ibid., 147)

I take seriously Klemmer et al.'s urge to reflect on the consequences of digital simulation of analogue, physical or mechanical processes, techniques and practices. There is no simple replacement, no 'pure' musical intention that survives the translation from embodied, physical skill to computational simulation or automated output (whatever Zinoviev might have hoped for). They are simply different techniques with very different musical outputs. For most musicians the sampler and digital audio have completely replaced the older tape music practice and, although I'm certainly not advocating a disavowal of the newer technologies, there is, I believe, much still to be gained from working with the *resistant materiality* (see footnote 16 above) of the tape music environment. As I can attest from the time I've spent engaged with tape music, the combination of tacit knowledge, gesture, risk and commitment provides a very different cognitive environment for technological musicking than one predominantly revolving around the digital computer. Cutting tape might be a 'hopeless procedure' if you want your electronic music to produce a pre-existing score with precise pitch and

duration,[73] but if your electronic music practice is interested in physical, embodied interaction with a material instantiation of electronic audio, then it can provide a very stimulating environment. If one is prepared to put in the time and effort one finds that the embodied cognition of the interdependent hand-ear-mind lead to the tape studio being an inherently "aesthetically potent environment" (Pask, 1971, 76).

In the next section we will broaden this potent studio environment out into the wider world of sound installations.

At play with the materials of tape

Around the same time as my studio-based tape music explorations, I took the materials of the tape studio out into the wider world in two sound installations. One was installed in a gallery, and one displayed at an evening of postgraduate music at Sussex. In both cases the materiality of tape itself formed the central focus.

In the gallery tape installation *The Long Loop* (2013) I designed an environment that invited an audience to play:[74] there were instruments to pick up and play, there was the tape loop feedback system to play with (either with an instrument or with the voice) and there was the space of the gallery to play; the whole thing was an ecology of playfulness.[75] The invitation was freely and spontaneously taken up, and the audience certainly seemed to be enjoying this playing for the sake of playing. The long loop, of the title, was some 30 feet in length, running between two rooms of the gallery, with a reel to reel machine at both ends. Track 1 on the first tape machine was set to record, and its output would be heard from track 1

[73] See also Born (1995) on how the rationalistic, formalist ideology of IRCAM in the 1980s enforced a similar disavowal of the empiricist, hands-on approach of *musique concrète,* and related analogue technologies, in favour of 'cutting edge' new digital technologies.
[74] On the importance of play to theories of craftsmanship see Sennett (2008, 269). On playfulness in HCI and interactive design see Gaver (2002).
[75] See http://euterprise.com/index.php/music-research/sound-installations/the-long-loop/

on the second machine. It took 15 seconds or so for the sound to travel to the other room and be heard, and audience members took some delight in following the physical passage of a sound they had deposited, moving to the second room to hear it. The principle operated in reverse for track 2 of the loop: recording on the second machine and then being played back 15 seconds later from the first machine. The microphones also picked up the output from the tape, and a low frequency feedback drone soon emerged that accompanied the various sounds the audience added to the live mics. The audience showed a fascination with the actual materiality of the tape: the way it wobbled as it moved, the way they could follow sounds they had recorded from room to room. The technology employed here is old: Pauline Oliveros and Terry Riley were exploring similar tape delay systems in the 1960s, but to a contemporary audience the experience seemed fresh and engaging. I am quite certain that had the installation been set up in a similar way using digital technology (fairly simple to do) engagement would have been quite different, primarily because they would not have been able to follow the movement of the sound from one machine to the next. This physicality, this direct and palpable linking of the materiality of tape with the space of the gallery and the sounding environment, was key.

A second invitation to play, enthusiastically accepted by an audience of musicians, students and scholars, can be seen in the second installation *What Are the Benefits of Sound?*[76] The rather curious title came from a conversation prior to the opening of the show that I had with a media student. He said he'd like to interview me, and would probably ask questions such as "what are the benefits of sound?" As a musician and composer who is obsessed with sound, the question was disconcerting, hilarious, and perfect for the title of the piece. In this installation the tape loops are locked up in 'endless cassettes' (originally used for answerphone messages and the like), deposited into cheap portable cassette players, suspended from the ceiling, each with a toy instrument attached. There were six of these hanging sound stations distributed around the performance space. Audience members could intervene into these loops (prerecorded single notes from the toy

[76] See http://euterprise.com/index.php/music-research/sound-installations/what-are-the-benefits-of-sound/

instruments) with their own recordings, by stopping the tape, pressing record, depositing their contribution, pressing stop, and pressing play. Their intervention couldn't be heard until the loop went round its minute-long cycle (neither rewind nor fast-forward function with endless cassettes), but participants generally didn't stick to individual cassette machines long enough to listen to their contribution, tending to be part of a faster moving dynamic through the whole space. The messy, noisy, participatory environment was enthusiastically engaged with by an audience who latched onto the simple procedure and the complex, chaotic emergence; who seemed to enjoy exploring both the physicality of the tape/instrument coupling and the social space of the installation; and who seemed to be focused primarily on play, fun and performance. Here, again, we see the pursuit of underspecified goals (play for its own sake) as leading to interesting examples of emergence in potent aesthetic environments.

The tape music work, discussed above, formed an invaluable bed of know-how for the later tape pop production discussed in chapter 6. There were certainly things that I could have gone on to develop from the two installations, but in the meantime I discovered cybernetics, and so I laid down a path in walking to exciting and, to me, uncharted territories, as mapped in the next chapter.

CHAPTER 5: PRACTICE (2) – MODULAR SYNTHESIS PERFORMANCE

Chapter summary

The chapter explores performative modular synthesis environments that feature complex, nested feedback networks. Early work attempting to create self-organisation through self-playing modular systems was unsatisfactory: once set in motion they did not exhibit an increase in order. A system was devised that required a performer to navigate zones of sonic interest: *The Thing Breathed* was performed in public multiple times. Such zones are obscure due to the multiply nested feedback paths. Performance is real time search for these rare zones. The system is a black box, impenetrable to direct articulation of the performer's will. The modular system is viewed as 'maverick' computer, in line with Pask's expansion of the nature of computation beyond the confines of digital devices. Such hybrid devices are better able to compute *concurrent* operations. The concerns of the chapter are thus part of the larger concerns of the thesis: the questioning of the ubiquity of digital devices in contemporary musical composition and research. The physical nature of the modular system is discussed, highlighting a primarily aural modality, and how emergence comes from the interconnections of simple elements. Concurrency in the system encourages direct interaction with the bringing into being of sound. Pask's maverick electro-chemical computer, the 'ear' is discussed and paralleled with *The Thing Breathed*: it is impossible to stipulate where 'control' is manifest in such a system; typically distinct elements of modular synthesis are blurred in the interlinking of control signals with audio signals; co-constituted feedback paths add to this occlusion. The system resists analytical penetration, performing a 'dance of becoming' that cannot be pre-programmed or predicted, except in terms of high-level tendencies. The performer's memories of sounding behaviours, activated in conversation with the modular system, are deeply 'burnt in', indicating a high level of engagement and foregrounding embodied processes of listening. Injection of requisite variety comes from neither random generators or environmental perturbations; it comes from non-linear iterative processes instantiated in analogue electronics.

Introduction

> Admittedly, we enter into a strange world, continually evolving but continually conserving all that has gone on, as fractal traces. It is, for all that a very beautiful world, at least insofar as I am able to glimpse it. (Pask, 1992, 57)

The work discussed in this chapter explores performative modular synthesis environments built around complex, nested feedback networks. This work coincided with my first blush of excitement researching cybernetics, but also continued concerns from the previous chapter such as alternatives to ubiquitous digital technologies, embodied cognition, gesture and ergonomics, and physical, resistant materiality. Initially it addressed the idea of self-organisation (cf. p.77), through attempts to build 'self-generating' patches, as they are known in the modular synthesis community:[77] systems that 'play themselves', without the need for human intervention, while maintaining sonic interest, such as Douglas Leedy's *Entropical Paradise*, documented and discussed at length in Strange (1982, 244-247).[78] After initial experimental work in this area it became clear that a fully self-generating system was unsatisfactory, and a performer *would* be necessary, though intervention could be minimal at times. In practice wholly autonomous self-generating patches tend not to be self-organising: once they are set in motion they do not exhibit an increase in order. Though 'order' (from some perspective or another) may well ebb and flow in such pieces, and this may be a significant part of the piece's interest, over a sustained period order will tend to even out, and the piece will not demonstrate evolution or adaptation to a changing world. In general, the self-organising aspect of a self-generating patch will be in the initial 'discovery' stage, putting the system together, a long, often circuitous process whose goal-directed nature encourages evolution (though the desired state of 'sustained sonic interest' is necessarily subjective and goals are underspecified, in the manner of Pask). One such evolution is shown at http://euterprise.com/index.php/music-research/modular-synthesis/self-generating-modular-systems/, which charts the various different systems I

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[77] Particularly among the denizens of Muff Wiggler, the pre-eminent modular synthesis forum (muffwiggler.com). See, for example: https://www.muffwiggler.com/forum/viewtopic.php?t=31698&postdays=0&postorder=asc&start=0&sid=f178425b4978dc36ac1d34f7d5d35ec3

[78] Strange calls such systems "self-playing dream machine[s]" (1982, 244).

explored before finally arriving at the piece *The Thing Breathed* (*TTB*), which has been performed in public eight times. In this piece the performer is necessary to move between the zones of sonic interest, zones that are often hard to come across, but that burnt themselves into my musical memory as I conversed with the system in rehearsal and performance. The search process, effected through twisting knobs, moving faders and listening, became the piece: how to move from one interesting area to another and form a satisfying structure. Video, audio and photo documentation, plus a detailed technical description of the system are shown here: http://euterprise.com/index.php/music-research/modular-synthesis/the-thing-breathed/

Even though I put the *TTB* system together and perform with it, patching cables and turning knobs,[79] the locus of the multi-way interaction is a *black box*[80] to me, and I cannot directly impose my will on the system; I cannot directly 'write' the result I desire. I have to work with it, coaxing fruitful zones of exploration. It means accepting the limitations of the equipment; going with the grain of the materials at hand rather than trying to subject the material medium to the will, the score, the plan, the program. In this way, the interaction feels more like a conversation, and we must learn each other's tolerances and predilections in order to reach some form of consensus. Of course, being the one who will be final arbiter of consensus, I have an important element of control in the relationship, but if the questions I am asking are about the machine's fitness for autonomous operation, then we have a chance, through sound, to explore *control* itself, and the nature of the devolution of control in human-machine interaction. These are notably cybernetic concerns, and the point is that they can only be addressed through a performative unfolding of the system, since the complex nature of the feedback network precludes analytical penetration, resists being separated out into constituent parts, and makes pre-programming an intricate, unpredictable

[79] 'Wiggling', as they say at Muff Wiggler.

[80] "The black box is a way of saying we cannot know what goes on inside any system, we have only our descriptions of behaviours we set up and observe: and when we find regularities, it is in the behaviours of the black box *vis-à-vis* our observation and interpretation as and when we interact with it" (Glanville, 2001b, 654). See also Rabardel (2002).

balance of memory and contingency. In ongoing interaction one must allow the machine its agency, one must let it be as it becomes.

Modular synthesiser as maverick computer

The Thing Breathed and related work uses analogue modular synthesis to navigate terrain more usually explored today through digital means. Pask's confidence in computation (broadly writ, and not, in general, restricted to digital systems), and his practical use, throughout his career, of 'maverick' computer systems, provide an illuminating parallel to the non-digital methods of exploration discussed in this chapter. In *Micro Man,* Pask and Curran's non-technical book on computing from the early 1980s, and prefiguring academic work on the post-human by a decade or so, Pask declared his confidence that the human-computer relationship could be a hugely beneficial symbiosis:

> Our hope – and our belief – is that the two species [human and computer] will co-operate, and that by doing so they will continue to enrich each other's continuing evolution. From this mutual accord there could emerge a metamorphosis, a transformation both of the human mind and of the nature of computing, leading to the genesis of a novel, interdependent pair of species. (Pask and Curran, 1982, 3)

But, as we saw in chapter 3, Pask's notion of computation is not a standard one. Pask's general optimism in *Micro Man* about the future for these new species is tempered throughout as he urges us to take seriously our own part in shaping this mutual evolution, and cautions that the conventional architecture of the digital computer may not afford as much as we might hope: "At present, the computer is limited in two ways: by its architecture – the ways in which it can manipulate numbers and symbols – and by the fact that not all of reality can be modeled in terms of numbers and symbols open to logical manipulation" (ibid.). We will recall from chapter 3 that Pask did not believe the standard von Neumann/Turing digital computational architecture to be capable of computing the kinds of concurrent processes that lay at the heart of Conversation Theory, such as learning, abduction, analogy construction or the creation of (shared) knowledge.

I take seriously Pask's directive to play a part in shaping the world, and am attempting, in my practice, to cast some questions on the ubiquity of digital computing devices, and on the seemingly unshakable faith large aspects of contemporary culture place in them. *The Thing Breathed* addresses areas which are currently, for the most part, addressed through conventional computation: A-life concerns like emergence, adaptation, and of course, liveness itself; cybernetic concerns like boundaries of systems, signal flow, feedback, homeostasis. But in my case, the interest in performative emergence, and the desire for fluidity of boundaries in conversational musical systems, has been most satisfyingly answered through use of analogue modular synthesis. Truly complex and fascinating zones of sounding behaviour can be reached through the interconnection of relatively few, simple modular elements, and in performance my interaction with the system involves twisting knobs, riding faders, and often just listening. I find this tactile/audile ergonomics preferable to the interface of the computer, where listening is so often accompanied by looking.[81] I like that my modular systems don't have a screen, that the focus of engagement is always primarily aural. Also, and crucially for me, as a musician creating performance systems, there is no lag as processing happens, because all processing is concurrent. There is no sequential ordering of constituent parts or events, there are no interrupt routines. There is a flow and a coming into being. Of course, the A/D converter – processing – D/A converter lag is a byproduct of one of the digital computer's huge strengths: if you can make recorded sound (almost) immediately available for manipulation, then you have a very powerful system for having a conversation with a processed historical version of your own sound making, and much excellent electro-acoustic music has been made in this vein; but if you are more interested in the bringing into being of sound, and a direct, concurrent interaction with that becoming, then this lag can present some serious problems.

This bringing into being of sound in *The Thing Breathed* displays a palpable 'liveness', which manifests in the tight linking of order and unpredictability, and

[81] And where I find I already spend so much of my time – writing this thesis, researching, teaching, communicating with others, being entertained, etc.

seems to echo various natural processes. The chaotic, non-linear dynamics of the multiple, mutually interacting feedback paths instantiated in analogue electronics – nested chains of continuous transduction – allow for predictable large-scale rhythmic and timbral tendencies, but preclude moment to moment anticipation of the behaviour of specific details. Somewhat like the difficulty of trying to predict how a cloud formation will develop, or when the next drop of rain will land on one's left ear. In *Micro Man* Pask points up possibly fruitful and under-explored links between natural, biological processes and computation: "Because of the success of the microprocessor, it has become conventional to see computing generally in terms of micro-miniaturized electronic circuits. This has had the effect of stifling computer designs that do not necessarily require electronic components at all. Biotechnology offers one such design possibility" (Pask and Curran, 1982, 24-25). A bio-computer would be a "maverick" in Pask's reckoning, and the whole chapter of *Micro Man* devoted to bio- and other maverick computing systems indicates the importance Pask placed on these unconventional alternatives. I think it highly unlikely that other 'introduction to the computer' books of this period would have mentioned, or even been aware of, these alternatives. It seems clear that Pask's germinal, practical experiences with chemical and biological computing in the 50s had a lasting influence on his thought. Both Musicolour and the electro-chemical 'ear' appear in the *Micro Man* chapter on mavericks, as does a picture of a pond, with the caption: "A real-life modular processor?" (ibid., 143), indirectly referencing Pask's collaborator Stafford Beer's work.[82]

The maverick computer that Pask built in the late 50s, dubbed Pask's 'ear' by Bird et al. (2003), consisted of an electro-chemical solution, with several conductive elements inserted into the solution that act as inputs and outputs. Currents are drawn through the solution and deposits of metallic iron threads grow in the solution, tracing paths of least resistance to current flow. These 'dendritic' threads in the ferrous sulphate solution are unstable and grow unpredictably. They dissolve and reform rapidly and flexibly, and as the network of dendritic branches forms over time there is an indication of "how such a system might be seen as

[82] See Pickering (2011, 231-4) on Beer's experiments with biological computing and his attempts to co-opt an entire pond ecosystem as an adaptive controller.

conducting a search through an open-ended space of possibilities" (Pickering, 2009, 481). Pask managed to 'train' this system to differentiate between two different frequencies of sound – through the direct interaction of the sound waves with the sympathetic vibrational properties of the dendritic threads, a transductive relationship – without the need for any kind of additional interface, such as a microphone. The dendritic network vibrated differently in response to the changing frequency of sounds in its vicinity, and Pask's 'reward' system entrained the dendritic growth to act as a filter between the two desired frequencies. This is very different to the much more usual case of an external sensor 'bolted on' to a robot or digital computer; here the sensing emerges from the actual computing substrate itself. Stafford Beer, who collaborated with Pask on the cybernetic ear, commented:

> This was the first demonstration either of us had seen of an artificial system's potential to recognize a filter which would be conducive to its own survival, and to incorporate that filter into its own organization. It could well have been the first device ever to do this, and no-one has ever mentioned another in my hearing. Moreover, this facility would transform the world of information technology, if it could ever forget and transcend its origins in mere data processing. But that would require the overthrow of yet another paradigm. (Beer, 2001, 555)

Beer goes on "Meanwhile, back in the pre-computer 1950s…" to make clear just what paradigm he would like to overthrow. Pickering speculates that "the long trip through chip manufacture and digital computation certainly appears as a massive detour" (Pickering, 2009, 489), in reference to Beer's related concept of "the infinite computing power of nature", and echoes Beer's wonder at the ear:

> There is something truly remarkable about this episode. I can think of no equivalent in the history of Modern science and technology… It is common enough in the history of electronic computing to add senses to a machine—Grey Walter made it possible for his tortoises to hear by wiring a microphone into their circuits—but this has always been by design, something imposed from the outside by the designer. Beer and Pask, in contrast, simply exploited the inner agency of their adaptive Black Box—a possibility which I think could not even be imagined in the Modern paradigm. One way to see what is at stake here would be to say that the Modern detour through knowledge and away from the world can also be a block, a trip that forecloses options that Beer and Pask's work demonstrates lie actually already at hand. Perhaps we are more impressed by this technoscientific trip than we should be. (ibid, 486)

Pask notes how, in the case of the ear and related devices, "there is no clear boundary between programming and adaptation" (Pask and Curran, 1982, 141). If one wanted to use such a biological or chemical computer as an automated adaptive controller, then one would have to work with the controller, interact with it to learn its ways in order to be able to 'train' it in a mutual to and fro conversation that involves compromise and accommodation. To program the ear, as Pask did when he trained it to differentiate two frequencies, means working with the adaptive dendritic growth in response to stimuli. "The very ambiguity of devices like this has important implications. Because it is not easy to decide which components respond to vibration or which components compute the conditional reaction, the whole question of where the computer's boundaries lie becomes deeper and more complex" (ibid., 135).

This questioning of boundaries, particularly where complex systems interact such that it is impossible to state clearly where control is manifest, runs through much of Pask's thinking, and resonates with the ambiguity and unknowable nature of systems such as *The Thing Breathed*, where multiple feedback paths occlude the distinction between the production and the processing of sound, and between 'sound' and 'control'. My rational mind, steeped in the standard pedagogy of modular synthesis, is good at the top-down thinking that understands the difference between an LFO that outputs a control voltage (CV) and an oscillator that outputs an audio signal, and is happy to draw the distinction between their respective functions as 'modulator' and 'producer' (of sound), and the related distinction between a control signal and an audio signal. The distinction will be maintained in the labeling of inputs and outputs – the LFO may have a CV in, to modulate its frequency, and will have a CV out, so that its frequency can modulate another device; the oscillator will have a CV in to modulate its frequency and will have an audio out. But this distinction is instantly complicated by feeding the audio output of an oscillator into the CV input of an LFO, which in turn sends its output to the CV in of the original oscillator. At this point it is impossible to say which is controlling which.[83] The addition of only a few modules to this kind of

[83] The first, 'simple' system, documented at http://euterprise.com/index.php/music-research/modular-synthesis/self-generating-modular-systems/ explores this kind of ambiguity of control.

feedback network, and where control and audio signals are mixed up, makes for a system of high complexity that resists attempts at analytical understanding, and performs, in the present, in a dance of becoming[84] that can't be pre-programmed, and can't be predicted, except in terms of tendencies and patterns of organisation. For me, as a musician, this establishes a potent environment for conversation, because it gives the machine a real chance of agency as we converse. Direct 'wiggling' with the system affords the opportunity to ask questions, and some of the most productive questions have been about the fitness of the system for autonomous operation. I'm asking the system to do as much as it can on its own, without needing me to intervene. Wiggling is, of course, programming, and the behaviour I am trying to program is sustained sonic interest with rich possibilities for the evolution of these engaging sounds, textures and rhythms. There is a sense in which I, the programmer, am being programmed, as I gain familiarity with the various combinations of settings which could lead to interesting behaviour, and begin to map these zones in my mind – a mental laying of breadcrumbs. I have the sense of being an explorer in a strange sonic topology[85] where one can chance upon a rich seam of complex evolving rhythms and timbres, and where very small adjustments of knobs can lead to wild lurches of behaviour. Later, the memory of these temporal and timbral patterns will lead me to search for the zones again, not infrequently unsuccessfully. One of the really interesting things is the depth to which these memories seem burnt in, and it is a very exacting arbiter that often says 'no, that's not the same' to the results of the search. The very strong and distinct nature of these musical memories indicates a deep engagement both with the processes of exploration in sound making, and with the *listening* at the heart of these explorations. Each performance of *TTB* navigates this strange sonic topology, and as I write this, months after the last performance, years after the first explorations, I can still clearly hear some of its most distinctive sounds and textures.

The use of feedback networks in analogue circuits to make music is not new: Strange notates two in *Electronic Music* (Strange, 1982, 84 & 244), and the practice

[84] In the sense of Pickering's 'dance of agency' – see for example Pickering (2007, 44).
[85] "Topology investigates questions of connectivity and boundaries" (Barad, 2003).

loops back through David Tudor and Nicolas Collins, at least as far as the Barrons' self-built electronic circuits used to create the music and sound effects for the movie Forbidden Planet.[86] Most research into autonomous musical environments is currently conducted through digital or digital/environmental means (see Holopainen (2012) for a comprehensive overview). Modular synthesis is not, in general, subject to the same narrative of obsolescence that we will meet in the next chapter, but it may still appear odd or even perverse, to some, to insist on the continuing relevance of 'old' technology, to deliberately *not* use whatever technology is currently deemed 'cutting-edge'. But I believe there are important parallels with Pask's wish, espoused in *Micro Man*, that we don't forget the important lessons to be learned from obsolete 'mavericks' about the nature and possibilities of computation, and that by widening the scope of our definition of 'computing' we might begin to get beyond tired analogue/digital polarities and the succession logic that continues to promote digital technology to the vanguard.

The modular feedback system of *TTB* is a 'deviant' computing system, and from a conventional perspective makes quite a poor computer: it is barely programmable, and recall of 'pre-programmed' states is a hit and miss affair; its unpredictable, chaotic behaviour makes it impractical for representational duties; its powers of calculation are limited. In what way then, is it a computing system? It is a maverick, in the sense Pask described in *Micro Man*. In working with the modular I am looking for a human-machine entertainment-entrainment system, something that might do some justice to the legacy of Musicolour, "the first coherence-based hybrid control computer" (Pask and Curran, 1982, 144). The modular system directly computes, through the "active fabric" (ibid., 139) of the continuous flow of electricity, the areas of musical activity I'm interested in exploring: variety in repetition; rhythmic complexity amid structural stability; rhythmic/structural/timbral interdependence; concurrent interaction of multiple elements; ambiguity around the locus of control.

[86] For Collins, see Collins (2011, 2002); for Tudor, see Nakai (2014); for the Barrons, see Dunbar-Hester (2010).

Neither random nor perturbed

One of the things that sets *The Thing Breathed* apart from many of its self-generating antecedents and from other feedback systems, is that variety is injected into the system from neither random generators nor from environmental perturbations. As Pask noted:

> It is clear that haphazard perturbations… may contribute variety to the system, but they are inessential, the predictable chaos of non linear, iterated, processes, approaching a chaotic attractor would provide sufficient variety to suffice, were there no perturbations from an outside. (Pask, 1992, 35)

In terms of synthesis we may read "haphazard perturbations" as random generators, and many attempts to create self-organising or 'life-like' behaviour[87] in synth patches employ random components, just as many environmental feedback systems inject perturbation from the unpredictable contingency of the environment. For example, the two self-generating 'dream machines' in Strange (1982, 84 & 244) both use one or more random voltage generators; Collins' *Pea Soup* (Collins, 2011) and di Scipio's *Audible Ecosystems* (Di Scipio, 2003) both employ feedback paths between the environment and the system (through microphone/system/speaker couplings) to form self-organisation and variety. But Pask reminds us that systems themselves can be lively and "of sufficient variety" if they have non-linear iterative processes at their heart.[88] *The Thing Breathed* uses neither random generators nor environmental contingency to achieve its variety and liveness, instead it relies on its inherent internal non-linearity, residing in iterative, circularly causal, multiply nested chains of interdependent continuous transductions.

The contemporary synthesist whose work *The Thing Breathed* resonates most strongly with is Jessica Rylan. Her self-designed and constructed analogue modular synthesis devices are presented as black boxes. There is no 'legending' on the fascia, and the 'manuals' themselves are terse, conversational, and seemingly

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[87] "Self organization is often, and rightly, considered to be an index of animation; the extent to which a system is living" (Pask, 1980, 397).

[88] See also Pask (1971, 76) on how "sufficient variety" is one of the attributes of "aesthetically potent environments".

deliberately under-analyse the workings of the devices: "The most important thing is to try a lot of different combinations, and don't be discouraged if you don't find what you want straight away. Because when you do find the magic spots, it makes it all worth it!" (Rylan, 2008). This directive to search, to explore, not necessarily to understand, but to become to know the system is an important part of the interaction with her devices. Like *The Thing Breathed* there are sweet spots of interest, or aesthetic potency, in Pask's terms, but their locations are not obvious, and the process of finding them is not necessarily rationally explicable.

The desire to 'understand' through analysis is a strong element of the history and theory of modular synthesis. Muff Wiggler founder Mike McGrath said this of his own modular system: "what I love about it is quite often I play with it and it surprises me by doing things I never thought it was capable of, and they make me stop and figure out why did that happen, and I need to understand analytically now why it responded this way" (Botstein, 2014). This impenetrability to analytical understanding is exactly what interests me, though McGrath's desire to open the black box is part and parcel of 'learning the system', and a strong component of the pedagogy of synthesis: "It is essential that the musician understand the difference between the signals and controls – signal is sound and control is structure. Both are voltage activities, and what is musician A's sound may be musician B's structure. For musician A and B to perform efficiently, however, each must be very certain in his own mind about the flow of these two kinds of information" (Strange, 1982, 33). Strange does point up that the boundaries between signal/sound and control/structure are not fixed, but still insists that the musician must understand where those demarcations lie in their own systems. Both Rylan's and my patches question this boundary marking.

The language Rylan uses to describe her devices, and others that interest her, directly echoes my own hearing of *The Thing Breathed*: "The most interesting Serge[89] module is this kind of magic thing, called the Smooth/Stepped Generator. You can run noise through it and it generates these neat fluttery patterns. You get these very reality-sounding time frames and repetitions, the kind of natural

[89] Pioneering modular synth designer Serge Tcherepnin.

patterns where it doesn't repeat exactly but it stays within its range of motion" (Rodgers, 2010a). This could serve as a very good description of what I have encountered performing *The Thing Breathed*: lively, sometimes 'life-like', behaviour where small scale details are completely unpredictable, but exist within cyclic frames with definite predictable tendencies; and where the areas of sonic interest, the aesthetically potent tendencies, have to be searched for, and are chaotic in their sensitivity to initial conditions. This search *in* the performance, and from time to time it fails, or falls flat, but often enough it surprises and even delights both me and its audience.

CHAPTER 6: PRACTICE (3) – TAPE POP RECORDING

Chapter summary

The chapter details tape studio production of four songs: the Euterprise EP. The music is produced under the rule: *no digitisation of audio*. The point of the rule is to establish what can be learnt about both analogue and digital recording through removal of the element which is ubiquitous in contemporary pop music production: digital audio. Practice-based work in the tape studio coupled with extensive experience in the DAW studio allow comparisons between the two domains. Despite the centrality of an analogue recording medium, various digital processes are still evident in the tape studio: buttons and switches, clocks and triggers, digital documentation (including special case documentation involving the DAW), and digitally mediated studio research. The tape studio work is not an attempt at 'analogue purity' and lays no claim on being 'closer to nature'. Despite a prevalence for analyses based on the notions of nostalgia and authenticity in much current scholarly work on the recording studio, particularly where 'vintage' equipment (such as a reel to reel multi-track) are foregrounded, this work questions, and ultimately refuses, the usefulness of either term. Pervasive progress narratives in scholarly work on the historical transition from tape studio to DAW studio are questioned, and the importance of skeuomorphic emulation in service of such progress narratives is highlighted. Increasing orders of traditionally performed elements of the tape studio are formalised and instantiated in the computational domain of the DAW. Fundamental differences between editing in the tape studio and in the DAW are highlighted: these are seen to be differences in kind rather than of degree. Conclusions drawn from the tape studio practice highlight the following areas: *Commitment*: all performance (musical and technical) in the tape studio manifests commitment in action. Versioning, undo, and the hyper-plasticity of digital audio in the DAW studio leaven such commitment. *Performance and editing*: on tape, for something to sound like a performance it must be a performance. In the DAW, emulation, correction and construction of performance are commonplace. Correction in the tape studio always involves further performance. Even tape editing involves gestural performance on the part of the engineer. Visualisation of waveform in the DAW does not require performative commitment. *Decision-making*: the making of decisions happens constantly in the tape studio, and is a much more heavily weighted part of the ongoing production than tends to be the case with the DAW. Decision-making in the DAW tends to be deferred to a final construction phase (the mix), and is often not concurrent with actual performance. *Contingency*: on tape, the song in the making is highly context dependent, and issues such unpredictability, error, deviation from a plan, and the uncontrollable

> are often tightly woven into the final sound of the production. The DAW affords the possibility of exerting total control and eliminating contingency. *Listening and gesture*: despite the DAW attempting to present itself as isomorphic to the tape studio through skeuomorphic emulation, such assumptions miss essential differences around modality, gesture and how the embodied agent moves around the space of production. The tape studio is the domain of the ear. Once waveforms become visualised in the DAW we start 'looking at sound'. Such ocularcentrism changes the nature of embodied musical cognition in the studio. The 'at handness' of the ergonomics of the tape studio foregrounds gestural choreographies and an embodied engagement with the dynamics of the studio.

Introduction

This chapter presents practice-based research into pop music recording and production using analogue multitrack tape. The practical output forms an EP which will be the third Junior Electronics release,[90] and comprises four recorded songs. The making of these songs is documented at http://euterprise.com/index.php/music-research/euterprise-ep/.[91] The 'rule' behind the production of these songs:

Audio shall not be digitised at any point in the process from source sound to final product (vinyl or other analogue format).

No digital instruments, samplers or synthesisers are used - sound sources are analogue electronic or acoustic. All recording happens to tape: all tracking is to 8-track ½" multitrack;[92] this is then mixed to ¼" 2-track; the mix is then cut to vinyl

[90] Junior Electronics is the moniker of my solo pop music project. The first two releases (Junior Electronics, 2012, 2007) were made using the DAW.

[91] Within this page you can find the links to the very detailed descriptions of the production process of each of the four songs.

[92] The reason why I use 8-track is mainly financial: 16- and 24-track machines are still fairly expensive, and the 2" tape they use is very costly now. There is no doubt that the constraints of tape discussed here are made much tighter by using only eight tracks, but I do hold that with due care and diligence it *is* perfectly possible to make high quality recordings on this format, and, of course, some of the finest pop music ever made used eight or less tracks (though generally on machines that operate at higher spec than the 'prosumer' Teac 80-8 I have been using).

via an analogue mastering process. At no stage will tape tracks be dumped into the DAW for editing (a common hybrid process); mastering will not include a digital stage for procedures such as brickwall limiting (a normative contemporary procedure even for most recordings presented as 'analogue'); in other words, there will be no conversion of audio into or out of the digital domain.

The idea behind the rule is to see what can be learnt about recording, in its analogue and digital guises, by the removal of the elements that are, in contemporary practice, normative and ubiquitous: digitised audio and the DAW. Ironically, as a digital-audio-literate engineer, I've found that removing the DAW altogether is the best way to learn how it shapes and regulates studio practices. This removal forces one to confront, and places into sharp focus, those aspects of recording and production that have become second nature – such as micro-editing[93] and a primarily visual environment – and that simply don't exist in the tape studio.

Digital processes still in evidence

However, it is important to note, and in keeping the view of analogue and digital as complementary, mutually dependent, 'always and only coexisting', that digital processes and technologies are still much in evidence throughout the process. The following is a partial list:

1. There is extensive use of drum machines (with analogue sound production) that use digital memories, either programmable or preset. All such storage tends to be digital, since it is an instruction for where to place an event on a grid: this is not dynamic, 'more or less' information – the event goes *here* and only here – it is an all

[93] Micro-editing refers to one of the key affordances of digital audio and differs from the macro-scale editing possible on tape in two ways: (1) the ability to edit with extreme precision (down to the sample level) that comes from the ability to view the waveform and from the removal of physical constraints; (2) the ability to dissociate one track from another once it exists in the DAW – on tape you cannot move one multitrack element relative to another. The second is a fundamental, and frequently downplayed, difference between the two production environments of tape and DAW.

or nothing statement that would be made more 'expensive' and less reliable if it utilised the approximations of a continuous milieu.[94]

2. All buttons and switches are, at the functional level (cf. p.46), digital, for similar reasons to 1. It makes no sense to ask 'how far down is this button pressed?' If that question needs asking then it is a very poorly defined switch. A button needs clear and unequivocal on/offness. This is especially vital on a device like a tape machine which has a fairly sophisticated digital logic matrix underlying the tape transport, which does important work like not allowing the machine to enter fast forward and rewind at the same time!

3. Clocks and triggers are frequently used to allow syncing of many different devices at once, often in the initial laying of a rhythmic 'bed' that other elements will sit on top of and reference. For example, a drum machine sends a clock signal to a clock divider which sends a ½ time trigger to an arpeggiator on a synth and a ¼ time trigger to another drum machine. If synchronisation of elements is important then time needs to discretised so that devices can lock to a common pulse. This is a good example of the synchronous coupling of otherwise asynchronous processes that Pask refers to in his definition of information transfer (cf. p.69). Interesting tricks can be played with clocking devices with different cycle lengths (phasing), or having one leg of the clock feed interact with some other, non-clocked process. [95] Tricks like this are rather more difficult to achieve in the DAW, where one is under the rule of the master clock.

4. Digital documentation processes have been used throughout. The iPod has an excellent camera and readily lends itself to easy, cheap and portable photographic and video documentation. For the sharing of this documentation, modern digital portals such as YouTube are also easy and convenient, with excellent potential reach. It is also important to note that this documentation is not neutral – it is part of the process of recording/building these songs: although (documentary, CCTV,

[94] See http://euterprise.com/index.php/music-research/euterprise-ep/letter-game/letter-game-606-patch-sheets/ for an example of the discrete programming grid of a drum machine.
[95] For a good example of this see: http://euterprise.com/index.php/music-research/euterprise-ep/substantive-hungry-trouser-word/#Rhythm_tracks

etc.) cameras have a tendency to disappear from consciousness when ubiquitous, here the camera is not set up in the corner of the studio and left to run throughout the whole session. When a piece of recording is to be done to tape I set up a camera to record all such attempts, so it is part of the working method, and I'm always somewhat conscious that my performance may, at some point in the future, be *seen* (deliberately contrasted to *heard*), and this may have some impact on how I perform.[96]

5. The DAW itself is also used throughout the process, but in very specific and restricted ways. The copying of 8-track tape to DAW allows for another type of documentation, as one can build a picture of how the tape evolved over time: some record of individual tracks can be preserved that are erased on the actual tape any time a bounce happens.

6. Digital processes are of course in evidence in much of the 'background' work to the analogue studio production: finding a manual for an esoteric piece of analogue kit online; researching mic positions on Gearslutz; listening to relevant musical examples online.

In short, this is not an attempt at 'analogue purity', or any such idea as being 'closer to nature/the past/life' (see Sterne (2016, 2006) and cf. p.39). The practice removes one digital aspect of procedure – digital audio – in the hope of learning something about recording and production, and about that digital procedure itself. It foregoes the obvious benefits and affordances of the DAW to ask some questions about those benefits and affordances, and to push at the boundaries between analogue and digital, building on the supposition that we might just have tipped the scales too far towards the discrete in our wholehearted embrace of digital *everything*. Analogue and digital always and only coexist – here, in the work of analogue tape pop recording, just as in all other aspects of our 'digital age'.

[96] In the video here http://euterprise.com/index.php/music-research/euterprise-ep/substantive-hungry-trouser-word/#Bass you can see me check the framing on the camera and then change position. This may have been a factor in the duff playing soon after.

Nostalgia and authenticity

It is important to note that this practice is not an exercise in nostalgia or authenticity. The former term, much discussed over the last twenty years, especially in relation to pop music recording (see, for example, Bennett (2012), Kirby (2015), McIntyre (2015), Williams (2015)), implies just the kind of periodising logic that this project attempts to question: the work presented here does not yearn for the past, does not believe that things were better yesterday, is not attempting to be retro, vintage, old school or any other term that valourises times gone by. Current academic work on the studio that draws on narratives of nostalgia often focuses on use of 'vintage' equipment, such as Williams' argument that "an element of nostalgia is present when 20th century machines are used to capture 21st century music" (Williams, 2015); or Théberge's comment that "the association of multitrack studios with the sound of much classic rock has, in the digital age, resulted in its own form of nostalgia for 'vintage' analogue gear" (Théberge cited in Kirby, 2015, 318). But as Samantha Bennett notes:

> So far, there is very little evidence that recordists and practitioners using vintage technologies or precursors do so due to fashion, trends, nostalgia or sentimentalism… [T]he attribution of vintage technology usage to nostalgia alone is deeply flawed and ignores more important factors such as musical and recording aesthetic intention on the part of the musicians and recordist(s), sonic characteristics of chosen technologies, client expectations as well as time and budget constraints. (Bennett, 2012, 14)

Bennett's reasoned account is a result of extensive conversation with studio practitioners and resists many of the implicit progress narratives that colour other contemporary accounts (though her persistent use of the term 'precursor' to refer to analogue equipment indicates an evident succession logic). For my own part as practitioner I can assert that nostalgia is not a motivating factor in the work presented here.

The notion of authenticity has similarly been heavily mined in studies of studio technology and practice (e.g. Auner (2003), Dickinson (2001), Knowles and Hewitt (2012)), and is, I'll admit, one of the terms I find most difficult when encountered, as it often is, in the mouths or writing of my students, where it is

generally used in isolation, as a stand-alone term that has meaning in and of itself: authentic (good), more authentic (better), less authentic (bad), not authentic (very bad). The idea that authenticity must be *relational*, that the object, process, performance, identity, what have you, can only be authentic in relation to something else,[97] seems to have been lost somewhere along the way, and I suspect the word itself is best consigned to an authentic metaphorical dustbin.

Still, the word exists and holds meaning for many. One of the more interesting treatments of the concept, and of direct relevance here, is from Simon Zagorski-Thomas, who discusses anxieties around "performance authenticity" which result from the affordances of digital micro-editing in the studio, where "a proportion of editing is done because it is possible rather than necessary – or even desirable" (2010, 206). These issues arose from "an observation several interviewees made", such as:

> Justin Scott – as a generic rather than specific story – sitting with an engineer who would look at the wave forms of his drum performance on a computer screen, at a scale where several centimeters of screen represented only a few milliseconds of audio, and correct inaccuracies in his bass drum timing through this visual representation even though neither of them could hear the difference. (ibid.)

The anxieties arise from negotiations around the question 'how tight to edit a performance', given that the DAW allows the whole gamut of responses, from 'leave it as it is, warts and all' to 'let's hard-quantise the entire drum track, and while we're at it let's nudge the overheads forward so the transients line up with the close mics'. Does leave-it-as-it-is equal authentic? Or does it just sound out of time? Does hard-quantise sound like a robot? Do we need to 'humanise' the quantise value? Should we leave *some* of the original timing in there (personality/feel) but *correct* the more egregious moments? Engineers, producers, composers and performers all have their ways of dealing with this anxiety, and it is a serious topic of negotiation in the studio. One of the results of working on tape is that the question simply never arises.

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[97] 'Authentic', related to 'real', is, I would argue, another substantive-hungry term. See Austin (1979), and cf. p.34.

This work is not an exercise in nostalgia or authenticity. In fact, this is not an exercise at all – it commits to tape, and to the world at large, a new Junior Electronics record. Of course, scholars are welcome to view this work in any way they choose, and if it fits, or gives support to, their theories of nostalgia, or authenticity, that is their prerogative, but it is not, as far as I can tell, the motivation for what I do.

Progress narratives[98] and skeuomorphic emulation[99]

> [D]igital audio technology is progressively substituting most devices and tasks traditionally implemented via analogue electronics and components. In this sense, digital audio technology may be considered to represent a progression of practices and techniques known during many past decades in electro–acoustics and audio engineering. (Mourjopoulos, 2005, 300)

The narrative that positions the DAW as successor to, evolution of, and improvement on the tape studio is a commonplace that has assumed the position of commonsense, such that it is rarely questioned. The quotation from Mourjopoulos above plus a short sampling give a flavour:

> [The DAW has] deeply broadened the process of music creation and reception. (Savage, 2011, viii)
>
> Due to the inherent micro editing and automation possibilities, a DAW exceeds the capabilities of a conventional studio. (Kirby, 2015, 17)
>
> After the DAW became the common recording and mixing environment the traditional studio model rapidly became an anachronism. (ibid. 269)
>
> Digital audio systems are quite elegant, suggesting that they easily surpass more encumbered analog systems. (Pohlmann, 2005, 20)
>
> Computers can quite easily assume the role of a fully-equipped traditional production facility. (Leider, 2004, 46)
>
> The DAW can effectively replace and encapsulate much or all of the functionality present in a traditional console- and outboard-gear-based studio. (ibid.)

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[98] I borrow this term from Tara Rodgers, whose "long-term perspective on the history of synthesized sound resists the linear and coherent progress narratives that characterize many histories of technology and new media" (2010b, vi).

[99] See the definition in footnote 17, above. See also Bell et al. (2015, 1) on the use of skeuomorphs as "analog audio metaphors" in the DAW.

These assertions all come from scholarly enquiry and all display more or less celebratory assumptions of progress; they all assume a logic of succession; several also posit an idea of replacement (of a specific piece of analogue technology by a digital version) along lines of continuity (the replacement 'does the same thing').

To make his point about 'technostalgia' and a contemporary fixation on "outmoded frameworks" (2015, 5), Alan Williams compares 'semi-solitary' producer/composers Prince and Trent Reznor, who he positions on either side of a historical analogue/digital divide. In the 80s Williams idolised Prince because he:

> seemed to have mastered all of the elements of music making in the analog realm. And he appeared to do it on his own… Had I grown up a decade later, I might have found Trent Reznor to serve the same purpose, though utilizing a very different set of processes. Reznor often operated within the semi-solitary template that Prince espoused, but he did it by rejecting many of the old school methodologies that Prince had employed. Primarily, Reznor's mastery of the non-linear editing possibilities that DAWs afford granted him a far greater compositional flexibility than his purple-minded idol. Whereas Prince performed to and alongside his programming, Reznor programmed recorded fragments of his performance. (ibid., 2)

But why should the 'constructive' approach of the DAW imply "far greater compositional flexibility"? One cannot deny increased *editing* flexibility, but that editing should be seen as synonymous with composition is a view that betrays a bias steeped in the computational culture of our time; it is a view that devalues contingency, performance and improvisation as essential parts of some compositional processes. And of course, this type of polarising comparison misses essential complications: Prince's use of the studio (like much studio production in the 80s) was hybrid – he used analogue *and* digital processes; he recorded to tape but used MIDI to lock instruments together; he programmed digital drum machines that sat alongside analogue and digital synths; he used sampling technology as well as extensive tape speed manipulation; he flipped tape over to produce reversed reverb, but the reverb was digital (Helmreich and McMurray, 2017). His *programming* of the tape studio (cf. p.71), alongside engineers such as Susan Rogers, was highly sophisticated, resolutely hybrid and showed a

technological flexibility and performative agility, both inseparable from his compositional processes, that has been rarely matched, before or since.[100]

To be sure, there is no questioning the 'periods of dominance' that these progress narratives lean on: the tape studio was the dominant mode of production from the 50s to the mid 90s; the DAW has been the dominant mode since the mid 2000s, with the intervening decade or so one of transition and hybridity. In that these periods coincided with the maturing of the respective technologies there is no doubt. In that this narrative posits inexorable technological and concomitant sociological 'progress', there is much that can, and, I believe, should, be questioned. The most commonly cited sociological benefits are those of 'democratisation', bringing the power of production to the masses, and the related ease of use or efficiency. Paul Théberge's investigation is one of the more insightful accounts: "'Democratization' came to be equated with the availability of consumer technologies and prefabricated music resources… The conflation of democracy, consumption and ease of use is, of course, a hallmark of contemporary capitalism. This ideology continues to dominate the promotional discourses of digital culture (musical and otherwise) in the early twenty-first century" (Théberge, 2015).

One of the most notable aspects of the ongoing evolution of the DAW is the way it has encouraged more and more of the traditionally performed elements of studio recording to be offloaded onto the computational domain. Performance here refers not only to the traditional role of the instrumentalist or singer, but also the many and varied activities of engineer and producer. Performative real-world studio activities include: musical performance; calibrating and operating hardware; editing; mixing; conversing with various personnel (musicians, writers, arrangers, etc.); and, of course, listening. All of these activities have, to some degree, 'benefited' from digital 'solutions' which automate, appropriate and assimilate the activities into formalised algorithmic representations. These, in general, appear in the guise of skeuomorphs which offer replacement along the lines of continuity,

[100] Prince's relationship with his studio Paisley Park is another high-water mark of the self-organising tape studio (cf. p.80).

and promise to remove or ease those aspects of studio procedure that are deemed 'difficult', 'hard to learn' or 'expert'. They are thus presented as beneficial, particularly to the (increasingly prevalent) 'amateur' producer. This process, present from the earliest MIDI specification that separated performance from instrument, shows no sign of letting up, and we are now witness to virtual performers, such as Logic X's 'Drummer', as well as machine learning based 'intelligent' mixing and mastering: "Mixing multichannel audio comprises many expert but non-artistic tasks that, once accurately described, can be implemented in software or hardware" (De Man and Riess, 2013, 1). But why are these 'tasks' considered 'non-artistic'? For many, the mixing process is one of the most creative and artistic parts of the job of engineering. 'Accurately described' here means formalisable, codable, and posits an idea of standardisation in music production which many bands, engineers and producers baulk at. That the machine learning process mines historical databases of pre-existing mixes indicates an irony at odds with the supposed 'innovative' nature of such software solutions: these automated mixes can only ever listen to the past.

We can read this, following (but inverting) Pickering and Barad, as a move from the performative to the representational (cf. p.19). This incremental incorporation of the physical, analogue and human elements of the recording studio into the DAW seems, with retrospect, to have followed an inexorable logic of convergence, and Sally Jane Norman's remark of 2006 has lost none of its relevance in the intervening 13 years:

> Digital information's propensity for atomisation, limitless duplication and recomposition, making it sensible and intelligible in a vast variety of ways, is the source of sometimes intoxicating visions of convergence: enthusiasm for the unlimited combinatorial potential of digital data distorts our understanding of the nature and representational function of digital resources, beguiling us into seeing infinite combinations of bits as blessed with a kind of omnipotence, namely the ability to relay, convey and ultimately be all. (Norman, 2006, 23)

Once audio is added to the micro-processor based MIDI sequencer and the DAW is born, increasing numbers of elements of traditional studio engineering become housed within the computer environment: the multi-track tape becomes multi-

channel digital audio; the analogue mixer becomes the virtual mixer; the studio 'rack', containing processors and effects units becomes available on 'insert' slots on the virtual mixer; the live performance of the mix, with multiple fingers on faders, becomes automation, which allows any element within the DAW to have programmed parameter changes in 'real-time'. Then instruments themselves get incorporated: initially this uses onboard sampling technology, but then physical modelling brings effective emulations of the Rhodes electric piano, the Hammond B3 organ, the Hohner clavinet – all classics of the pop canon. Physical modelling also takes in emulation of analogue synthesis, known as 'virtual analogue' or 'analogue modelling': hugely expensive and rare classic synths, such as the Arp 2600 or the Yamaha CS80 are available in multiple instances, all skeuomorphically rendered as 'authentic' emulations. Even amplifiers get digitised: amp simulators being common ways to 'get that sound', without the tedious need buy a decent amp, have it played at volume, or set up microphones on the amp to capture the sound. By this point, nearly the entire studio environment can be seen to have been swallowed by the DAW, except for three features of the traditional studio: microphones, loudspeakers and the personnel who operate the system:

The microphone, an analogue transducer, will continue to be valued in the studio environment, and no serious commercial studio will be without a selection, but the contemporary business of production does not *need* the microphone: samples, sound libraries, virtual instruments and performers played via MIDI, even Vocaloid software,[101] all mean that everything can be constructed within the DAW itself, without the need to ever record anything.

Loudspeakers: it is worth remembering, in the 'digital age', that the final stage a recording goes through before meeting the medium *we* listen in, the air, will *always* be analogue. DAWs may happily emulate a guitar amp in software, but the actual things we listen to the emulation on stubbornly refuse to be emulated.

Personnel: one of the more intriguing contemporary developments of this move from physical/analogue processes to ones instantiated within a computer is the

[101] See https://www.vocaloid.com/en

potential to remove the studio personnel themselves: in addition to engineers being replaced by automated AI mixing and mastering we also see the drummer's old adversary, the drum machine, raised to skeuomorphic heights in the latest incarnation of Logic, with 'Drummer' – a selection of virtual performers, handy little homunculi, each with their own 'personality' and subtle performance differences, always on hand to lend their expertise to your production. In effect, these demon drummers all sit in a little locker in the studio, ready and waiting to perform for you, all free from the pesky foibles that make real drummers potentially difficult to work with: these demons don't turn up late, they don't drink on the job, they don't have squeaky pedals, they don't ask for the drums to be turned up in the mix, they don't speed up towards the end of the song, they don't lock themselves in a cupboard and refuse to come out until *their* song is put on the B side of the single that's obviously going to be a smash…[102]

Time and again we see the changes the DAW brings being celebrated as liberating the user, of upscaling affordances, saving the engineer time, allowing them to do more, more quickly, more cheaply. One of the key changes was sold as 'vastly improved editing functionality', but even if the icon of the editing tool relies on skeuomorphic reference to physical work done with a razor blade (in Logic, for example, it is represented by a little pair of scissors), the affordances of digital editing are of a fundamentally different order to those of tape splicing. This is a difference in kind, not of degree: digital audio editing is a discretisation, a coding, a taking out of time, and this removal of sound from its dynamical milieu is neither predicted by nor develops out of analogue tape. On multitrack tape it is pretty much impossible to move individual track elements in relation to other tracks, and the only real editing possibilities are global: horizontal stretches of tape (time) can be sliced, removed, moved, reversed, but there is a limit to the smallest (shortest time) edit possible on tape, and it is of a vastly greater magnitude than the infinitesimal slice that digital audio affords.[103] This near infinite manipulability of sound, possible even at the level of the individual sample (typically one of 44,100

[102] Reputedly what Roger Taylor of Queen did to get 'I'm in love with my car' on the B side of 'Bohemian Rhapsody' (Irvin, 2007, 355). B sides take a 50% split of revenue.
[103] With tape editing it is possible to *cut* very small slices (1mm or so) but, as I can attest from experience, it is more or less impossible to put these very fiddly little pieces back together again.

per second) once it has become data within the DAW, is well known and much discussed. What seems to be less readily acknowledged, perhaps because it is hidden behind the skeuomorphs and the progress narratives that posit the DAW as the natural successor to analogue forebears, is that this ability, literally, to 'take sound out of time' is a radical, paradigm shifting break with analogue techniques and technologies – it is most definitely *not* a continuation, an upscaling of affordance or a necessarily logical successor.

Although this increasing virtualisation of the studio does seem to follow its own internal logic, that does not imply that this history is one of progress. Yes, digital audio has become better in quality as computers have become faster and storage has become cheaper. Yes, the studio can now become truly mobile and production can happen anywhere. Yes, the whole process has allowed for more and more people to make more and more music more cheaply and quickly: the monopoly of the professional studio, paid for by the record company, on making 'professional sounding' recording has gone. But does that necessarily equate to progress? Are there things we have lost as we have rushed headlong into this embrace of the computational? As Strachan notes:

> Computer-based music production enables and demands that the user work directly with captured and generated sounds that are at a remove from the processes and competencies of performance traditionally associated with musicianship… [T]he computer environment needs to be interrogated for the way that it allows, encourages and facilitates the making, processing and manipulation of sound. In other words, the computer environment should not be understood as a neutral way of recording, capturing and presenting sound but as highly influential to the creative process in its design, construction and capability which in turn have a central influence on the sounds and eventual recordings that are produced. (Strachan, 2017, *7*)

How are we to get to grips, in our actual studio practice, with the seemingly inexorable departure from the physical? What are we to make of this move away from the performative towards the representational? When even performance, historically one of the fundamental studio procedures, gets offloaded into the computational domain; when personnel, including, increasingly, the person of the engineer, seem no longer to be necessary for the production of studio recordings; when everything is made so much easier, cheaper and more convenient by staying 'in the box'. How do we make decisions about where to draw the line between

what we want to play and what we want a handy little homunculus to play for us, about how tightly to edit, about what we want to have direct, physical control over and what we're happy to offload onto automated processes?

My own approach has been to remove these questions, by removing the DAW and its little demons from the process. The following details that process and draws out some of the implications of a primarily analogue tape studio system. It will make comment on comparisons with the DAW along the way.

Commitment

> Where there is no risk and every commitment can be revoked without consequences, choice becomes arbitrary and meaningless. (Dreyfus cited in Klemmer et al., 2006, 145)

It is no accident that traditional studio engineers talk of 'committing to tape', and we noted in chapter 4 how Klemmer et al. cautioned that "digital artifacts often do not exhibit commitment to actions" (2006, 145).[104] Compared to the DAW, the lack of any kind of 'undo' or 'versioning' means that every move made on tape requires great care and commitment. It is perfectly possible, while recording, to press the wrong button, resulting in days' worth of work being deleted! Such risks force one to take great care, and to double-check everything before making critical moves. This added pressure does encourage a sharpening of focus which, in many ways, is a useful contrast to the somewhat blasé attitude often found in DAW recording which may well be sufficient where necessary attention to the task in hand is leavened by foreknowledge of versioning and undo.[105] No such distracted wandering of attention is possible with recording on tape: if you change something it is changed permanently, so you'd better make sure it is a change for the better.

[104] Winograd and Flores have also made commitment a cornerstone of their controversial attack on many of the assumptions underlying work on artificial intelligence (Winograd and Flores, 1987); see also Boden (2008, 846).
[105] See Duigan et al. (2010) on versioning in the DAW.

This sense of commitment is also, as discussed below, central to all taped *performance*: the knowledge that what you play is what the listener will hear; the knowledge that DAW style micro-editing is not an option; the knowledge that previous/better versions of a take may be jettisoned in search of the 'definitive' take. There is also greater commitment to the post-performance audition of the take: the performer records their take and sits with the engineer/producer to listen and decide if it's good enough, if it needs to be redone, or, where possible, if certain moments will be fixed through dropping in. The conversation between engineer and performer at this point will revolve around practicalities and contingencies: 'if we do another take what are the potential benefits and what are the risks?' The engineer will be encouraged to give as detailed as possible suggestions for *how* the performer is to achieve this: 'you seem to consistently have a problem with that melodic leap in the chorus – try to prepare for it mentally as you're playing that easy run down.' Or, 'if you cut that note at the end of the bridge short, we'll have enough of a gap to drop in, so you can relax about the end section and just concentrate on the first bit.' Engineer Carl Beatty, whose professional training occurred in the tape studio, and who witnessed at first hand the transition to DAWs, notes:

> [Of] all the things that I see that have changed drastically because of ProTools, the biggest one is communication. For the performers on the 'other side of the glass'… there's very little feedback from the producers, there's very little guidance in terms of performance, because they know they have acres and acres of 'real estate' to collect data, and very often the guidance is 'do another one'. From the world I come from, of limited real estate, 24 track analogue recording, that wasn't really part of the process, you had to be listening and making decisions as you go. (Beatty, 2007)

Discussing a similar situation, Richard Burgess (2013) cites Steve Savage's paper '"It Could Have Happened" – The Evolution of Music Construction', which relates the story of guitarist Warren Haynes, an extremely competent professional, who was in the studio to lay down a solo. He played three takes, and then left, "saying that he thought they had 'enough stuff' and that they should assemble the finished solo" (ibid., 157). In the end the artist and producer felt they couldn't construct a complete usable solo and had to get someone else to play over the last 8 bars.

> What is interesting is not that Haynes played badly – he is an excellent musician – but that he was happy to leave the final construction of the solo to the producer and the artist. The performer supplied the raw material and walked away without hearing the finished solo. Had Hayes still been there when they discovered the weakness in the last eight bars, within another take or two, he could have given them what they needed. There is now such familiarity with DAWs' editing power that consummate musicians are treating their parts as raw material rather than a fully crafted piece. This is interesting conceptually, but not if the end result is inferior. (ibid.)

Insights such as this are a useful antidote to the various assumptions of isomorphism that we encounter, such as: "In contemporary recording sessions, digital technology mimics that of older analog tape-based processes, so that for the performing musician the experience is nearly indistinguishable" (Williams, 2012, 1). Williams' article is noteworthy for the exploration of how the primacy of visual display in the DAW influences and regulates the production process, but fails to critically interrogate the deeper implications of the screen, choosing rather to celebrate how the shared screen, in a studio control room, affords participation: "Observing the ease with which an engineer can delete, repeat, stretch time, or literally 'flip it and reverse it,' the musician is given access to a staggering number of creative possibilities" (ibid. 3). Perhaps, but this also alerts the musician to the fact that there is far less riding on their performance than they might have thought. This is a liberation, of course, an easing of pressure, but it can also lead to an abdication of responsibility, a lessening of commitment *in* performance.

Performance and editing

> The actual process of analogue recording is by necessity far more focused on performance than digital recording. (Kirby, 2015, 361)

> Performance is the ground from which knowledge emerges and to which it returns. (Pickering, 2007, 44)

On tape, if you want something to *sound* like a performance it must *be* a performance. This is not the case in the DAW, where emulation, correction, or construction of performance are commonplace. Of course, the nature of performance to tape is different to that of live performance in front of an audience; the very nature of recording moves sound from the evanescent to the repeatable,

and there are all kinds of affordances in the tape studio that facilitate the recording of performances that musicians are happy to let out into the world, knowing that they may be listened to again and again. Traditional analogue recording offers: re-recording, until you're happy with the take; 'dropping in' to remove more localised errors; 'comping', which allows the compilation of various takes to select the best bits from each.[106] However, all of the above affordances involve *further performance* to correct unacceptable performance. Even comping requires a performance on the part of the engineer to swap between different takes on the multitrack, according to a pre-determined script, using mute buttons or faders, and also involves the inevitable loss of quality that comes from internal track bouncing. Comping in a DAW is free both from quality degradation issues and any need to perform: it is all achieved non-destructively on screen.

This is not to say that performance is necessary for *every* element of recording to tape: we have had sequencers, arpeggiators and drum machines since the 60s, all of which, apart from some aspect of programming, are automated devices that run themselves. A fixed microphone recording 20 minutes of Aeolian harp would involve no performance at all. It might be argued that the pressing of the record button is a performance, but this seems to deny the word performance of any useful specificity: pressing a button becomes a performance only when there is pressing need to push it at the right time, e.g. the aforementioned operation of mute switches in the analogue comping process, which must happen at exactly the right time in the playback/recording of the tape, or the pushing of some parameter change button on an effects unit during the mix. As noted in chapter 1, performativity is committed real-time activity which brings forth a world.

On tape, editing is intimately related to performance. This occurs on at least two levels: (1) The craftsman-like wielding of razor blade, chinagraph pencil, splicing tape and ears around the physical medium of magnetic tape is a performative combination of tacit knowledge and hand/ear/eye coordination that is mostly

[106] There is also macro-scale editing, which is possible with solo recordings, and is the technique that Glen Gould controversially championed in many solo piano recordings (Gould, 2004), but this is not possible with an individual take on multitrack, which is the primary form of tape recording explored here.

absent from the 'line the scissors up with the transient on the screen' type of editing common in the DAW. (2) Foreknowledge of the limitations of tape editing influences musical performance: if you make a mistake you know you will either have to live with it or replay it – there are none of the possibilities of localized post-performance editing that exist in the DAW, where timing errors are easily corrected by moving the event relative to the time-line, and errors of pitch can be corrected by DSP based 'solutions'.

Furthermore, on tape the decisions about whether to live with a performance, or attempt to correct it, directly feed into the *ʂound* of the performance. A take considered 'good' may include errors, but to fix these the previous performance (or parts of it through drop-ins) will usually be wiped. You can always re-record, but you run the risk of losing aspects that may never be as good. When, and how, do you decide the take is 'good enough'? How much time do you have? Does your playing get worse as the part gets 'stale'? The sound of the final take is often a compromise as well as a composite of all of these decisions made throughout the process, and may contain things you would rather weren't there, but seem like a better compromise than doing another take. This can lead to some recorded elements having 'rough edges' or even obvious mistakes, and puts the performer in a position of a much greater commitment to the performance than one tends to see in DAW recording, where there is almost always the option of 'fixing' mistakes later, and where you keep every version of a take so you can choose the best bits later. The place where I notice this the most on the Euterprise EP is in the singing. This is where I really realised how much I'd previously relied on the comping facilities of the DAW, where I would sometime comp individual syllables to keep all the notes in tune. I chose not to comp on tape, mainly because I didn't have enough tracks free to do it, so had to rely on dropping-in to fix tuning and other problems with the singing, and which you can't use to fix individual syllables. There are many rough edges to my vocals on the EP, which I certainly would have corrected in a DAW, which I have to live with for the reasons given above. This may be part of the charm of the record, but I leave that for others to judge.

However, it is important to note that micro-editing is not a *∂efault* in DAW production, though it is the norm in many areas of music production, such as pop

music. Where instruments are recorded simultaneously in the same space (and multiple microphones exhibit 'bleed') micro-editing becomes difficult, if not impossible, and thus many types of music, such as most classical music, and much improvised music, are not subject to the same kind of tendency towards construction and manipulation discussed here.

Decision-making

The making of judgements and decisions happens constantly during tape recording, and is a much more heavily weighted part of the process than is evident in most DAW recording. The interface and affordances of the DAW positively encourage the deferral of all kinds of decisions, from the compiling of takes once a performer has left the studio, to the oft heard 'we'll fix it in the mix'. Unlimited track number means that huge amounts of 'speculative' recording can happen, and large banks of tentative 'maybes' are often amassed before definitive arrangement decisions get made. The very tight constraints of multitrack tape recording mean that decision-making is an integral and necessary part of the recording process, and is thus intimately woven into the fabric of the recording in its becoming. This is perhaps the most important concrete result of this foregrounding of decision-making: the *sound* of the final recording is in a direct and contingent relationship with ongoing performative decision-making. This is different to the comparatively minimal impact ongoing decision-making has on the sound of a DAW recording. Of course, decisions get made in the DAW environment, but they don't necessarily, and in many cases tend not to, happen concurrently with processes of recording.

On tape, many of these decision-making processes are related to the restrictions of track count: internal bouncing of multiple elements fixes their internal relationship as they will appear in the final mix, both in terms of their relative levels and where they appear in the stereo field. Decisions taken about effects and processing of a track cannot be removed later. Decisions made about and during performance have a similarly pressing vitality, and have a direct bearing on how those performances occur. There is a considerable difference between the pressure

performers feel when they are wiping everything they previously did to get the best take, and the pressure they are put under when they can offload anxieties about 'best' performances onto a retrospective compiling of 'all the best bits' once the red light has gone out.

Much of this is related to the DAW's ability to take sound 'out of time', remove it from the ongoing temporal flux. This doesn't just affect things in the micro, moment-to-moment level of the temporal flow of the song, but also at the macro level of studio environment and recording process: the encouragement of deferral of decision-making in the DAW impacts performer, engineer and the ongoing evolution of the song in progress. The tight weaving in of decision-making to the fabric of the song in progress on tape will tend to result in a very different sounding final recording.

Contingency

> Ordinary life is necessarily one of situated, embodied agents, continually coming up with what to do faced with ongoing parallel activities in their various perceptuomotor systems. This continual redefinition of what to do is not at all like a plan, stored in a repertoire of potential alternatives, but enormously dependent on contingency, improvisation, and more flexible than planning. (Varela, 1997, 83)

> The good craftsman places positive value on contingency and constraint. (Sennett, 2008, 262)

On tape, however thoroughly we plan how the track is going to sound, however detailed and prescriptive the demo is, the song in the making *will change*. The becoming of the recorded song will have a relationship to, and dependence on, unpredictable soundings that are an inevitable and not always unwelcome result of performance, constraint and circumstance.

Contingency is the dependence on, and reaction to, the environment that one finds oneself within at a particular juncture – the knot that emerges unforeseen in the carving of a piece of wood. It is an inevitable part of the unplanned (and unplannable for) nature of reality in its becoming; the unpredictable, the error or

deviation from the plan, the uncontrolled/uncontrollable.[107] The hyperfluidity of digital audio makes it perfect for exerting total control, eliminating contingency; sound, performance, the song, become programmable, codable, and it is ironic to hear how often this coding is pressed into service in the production of an *emulation* of performance.

In the tape studio contingency is clearly related to decision-making in the construction of the recording, the becoming of the recorded song. Because decisions about arrangement, about sound, and about elements of the final mix cannot be endlessly deferred, there is a sharper focus on how each of the separate elements fit together into the evolving whole. The relationships between different elements assume greater significance than in the DAW because there is minimal possibility for shifting and altering how these elements fit together after they have been *committed* to tape. Editing/altering possibilities still exist, to be sure, but they are of a different order of magnitude than their DAW 'equivalents'. Thus there is a necessary ongoing focus on *listening* to how elements fit together, with a concomitant mental 'mapping forward' of how they will fit into the final mix.

Each element in the growth of the recorded song can be seen as being highly context specific, much more so than in the 'equivalent' building of a song in a DAW, where there is a tendency, arguably an encouragement, to accumulate elements that will be 'fit together' at some point later in the process. Tape has no truck with this deferral of decision-making – it insists one deals with contingency and context in the moment of making.

Listening and gesture

> [A]udio engineering practices are not reducible to one sense alone. Every widespread form of engineering developed until today has depended on the body for the manipulation of interfaces and on audition through headphone or loudspeaker audition systems. All computer-based audio engineering technologies depend upon the visualization of abstractions of sound and also a visualization of the interface for manipulating sound. However, scholarship on audio engineering has ignored the sensing body for the most part. (Bates, 2009, 1)

[107] "The uncontrollable offers us unimagined riches" (Glanville, 2001b, 37).

One of the things one notices when one removes oneself from the DAW and into the realm of its supposed forebear, is just how hard the DAW tries to ape the moves, processes and space of the tape studio through skeuomorphic emulation within the "square horizon" (Virilio, 1997, 90) of the computer screen. But consider a clutch of related assumptions: the assumption of similarity between the physical space of the tape studio and its virtual, logical 'successor'; the assumption that techniques and procedures move smoothly from one domain to the 'next' via a "digital switchover" (Buckley, 2011); the assumption that all that has changed is increased affordance, ease of use, efficiency. All these assumptions are misplaced, for they fail to recognise fundamental differences of modality, gesture and the way the "sensing body" moves around the space of production.

The tape studio is truly the domain of the ear: listening necessarily has primacy. When we consider the DAW arrange window as skeumorphic emulation of the tape head with tape passing by it, we downplay the important and fundamental change that happens to the engineer/producer/performer when waveforms become visualised. If we look at the tape passing by the head, there is *absolutely nothing to see*, just an expanse of black tape. When we start digitising audio and presenting it on screen in a manner seemingly analogous to the way tape passes the head something fundamental happens: we start *looking at sound*. This sounds like an oxymoron, but such language is common in activity around the DAW: 'I can see a silence here we can cut into', 'that master looks a bit over-cooked', 'it looks like you're playing consistently behind the beat'. All such pronouncements depend on a visualisation of waveforms (and the grid of the timeline in the last example). Sight is used in the tape studio: we look at meters to check levels, we visually line up pieces of tape we're editing, we look to check we haven't record enabled the wrong track by mistake. But sight carries significantly less weight than listening or gesture. The ocularcentrism of the DAW is manifest in countless ways, such as the visual editing that Zagorski-Thomas explores, or the 'visualiser' built into many EQ plugins, which I have witnessed students use to make the sound 'look more even': they turn the visualiser on and cut where they see peaks. In some circumstances this can help, in others it definitely doesn't, but one thing is for sure, it *teaches you nothing* about what an EQ does to sound: as the focus moves

from ear to eye, attention is diverted away from the actual aural effect, and we tell ourselves a tale of how we've made the sound 'look better'. I have witnessed a similar preference for the modality of sight in my students as they 'listen' to a mix: what they appear to be doing is watching 'blocks of sound' pass by on the screen, and if the screen is not in line with the speakers they will rather orient themselves towards the screen than the monitors.[108] Autechre, an electronic music duo primarily identified as 'computer musicians', point up how this focus on the visual can be a block to listening:

> There's nothing better than turning the screen off… When we're putting things down and mixing things and are trying to make things sound right, the screen has to go off… The worst things are the timeline sequencers where you can see on the screen what's coming up. That really fucks with your head when you're listening. (Tingen, 2004, no pagination)

Above I suggested that the visual modality is of lesser import in the tape studio than gesture, or gesturo-haptics, to use Brian Rotman's term, which folds linguistic and choreographic notions of gesture into modalities of touch and proprioception (Rotman, 2008). In the tape studio, these performative choreographies revolve around both learnt embodied routines, such as fader riding and tape splicing, and spontaneously created gestural solutions to engineering problems, such as raising a stringed instrument up to the microphone after it has been plucked.[109] This is a kind of 'manual automation' of later fader riding, an anticipation of how it will sound in the mix. Left as normally played, especially in fairly dense material, the harp in question has a tendency to 'plink' and then immediately disappear. This manual automation allows the tail of the sound to remain audible, and means it doesn't have to be done in the mix where hands are busy with all kinds of other moves. Tape editing is also a good example of the kind of gesturo-haptic/listening choreography where the 'rocking' back and forth of the reels is accompanied by a listening that needs to be expert to hear where the transient is (cf. p.86).[110]

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[108] This traditional, studio specific term for loudspeakers indicates how monitoring activity in the studio is an aural affair.
[109] See http://euterprise.com/index.php/music-research/euterprise-ep/letter-game/#Harp
[110] See https://www.youtube.com/watch?v=_VJxasayZSs&t=34s

What I'm alluding to here is an embodied engagement with the dynamics of the studio; a steering through the complex and resistant materiality of the studio environment that will not allow the bending of sound to the imperious will of the producer, but has to *go with* the multiply recursive and co-implicative trajectories and channels of that dynamic, through performative engagement and interaction.

> [T]he move to digital recording and storage reduced operational physical movement within the studio. It did not eliminate it, however. In an analogue studio the operation of tape machines and mixing desk faders required physical movement over a footprint up to the size of the studio itself. This has increasingly been reduced to a footprint the size of a qwerty keyboard and mouse mat, possibly retaining fader and other accessory input controls. Hence any residual idea of 'physical' performance is severely constrained… Less physical but nearly as constraining to body movement is having the eyes glued to the screen. (Emmerson, 2007, 26)

In the tape studio the various components tend to be (physically) organised ergonomically, according both to the needs of a particular situation, and established routines of practice. This 'at-handness' responds to gestural demands and tends to be flexible, modular, shaped by personal experience and in constant flux: new elements are bought/brought in, incorporated heuristically, modified by ergonomic principle or gestural facility; other elements are taken out as they are sold as no longer desirable, or according to economic expedient, or they break down and need to be sent off for maintenance, or they lose their lustre and get put back on the shelf. Further, elements can change their relationships with each other as unforeseen functionality is fortuitously chanced upon, as a synergy is uncovered, or as other working techniques from the wider engineering culture are incorporated into the setup. All such evolutions and adaptations are part of what this thesis refers to as the self-organising studio. The rhythm tracks of the four tracks of the Euterprise EP demonstrate these principles well, combining populations of different studio devices brought into local synchronisation. In all cases their synergetic interactions surprised and delighted me as I put them together, following the underspecified goal of 'interesting rhythm track'.

Tape pop recording

The key insights gleaned from this practice-based comparison of tape studio and DAW have primarily been to do with the nature of *performance* in the studio, from the perspective of both musician and engineer. The tape studio *insists* on performance, at multiple levels, and throughout all aspects of production. As well as musicians' performances, which require the highest levels of commitment, the craft of tape studio engineering is also highly performative: from calibration and operation of technology, interpersonal discussion and negotiation, craftsman-like razor-blade editing, through to the final mix. The tape studio is the domain of the ear, and of gesturo-haptics – the choreographing of embodied performative routines negotiating the resistant materiality of tape and its attendant technological milieu. By comparison, the DAW tends to devalue performance, by making micro-editing such a powerful and attractive alternative, by offering such flexible non-linear construction opportunities, by automating traditionally performed engineering tasks such as fader riding, by encouraging an accumulation of material to be assembled later, by endlessly deferring decisions about how the track is eventually going to sound, and through recourse to versioning and undo. The DAW studio puts far more emphasis on the eye than the tape studio; even the musician can see clearly just how easy it is to 'correct' poor performance, and is thereby abdicated from much of the responsibility of their own performance.

This performance-centric analysis also points up how the DAW relies on skeuomorphic emulation of the tape studio and its physical environment. We've seen how the succession logic that drives this emulation relies on narratives of progress, of increased affordance, of democratisation, and how it tells a tale of replacement along lines of continuity, as if analogue technologies' historical function has been to lay the groundwork for their eventual, inevitable incorporation into an all-encompassing digital realm. But this narrative occludes fundamental differences in kind between the tape studio and its supposed descendant. Rather than looking at the DAW as tape studio with added affordances, we should see the two environments as different in fundamental ways, and the practices that happen in these environments as leading to very different sounding music.

CONCLUSION

> Every act of knowing brings forth a world. (Maturana and Varela, 1992, 26)

The world that this thesis brings forth, participates in, and directs its cybernetic ears towards is one of constant becoming; a changing world, one that will not sit still awaiting explication, penetration or formalisation. Such activities are important, but they bring forth, at best, only half a world, one that can be identified with Pickering's "Modern ontology", and with various strands of computationalism, in particular, computational theories of mind that posit highly complex digital cognitive structures within our skulls, working primarily though symbolic representations of a world 'out there'. Howard Pattee is fond of quoting von Neumann – that celebrated progenitor of formality in its current dominant technological form, the digital computer – to much the same effect: "As von Neumann warned, if one studies only formal life, '…one has thrown half the problem out of the window, and it may be the more important half'" (Pattee, 1995, 2; the quotation is from von Neumann, 1966).[111] Pattee believes that the *creation* of formality is itself not adequately formalisable and suggests that such generative acts of cognition cannot be separated out from the flux of becoming, cannot be reduced to algorithmic or symbolic representation, and are thus beyond the reach of processes that exist within wholly digital environments.[112] His view suggests that an all-encompassing "faith in formalism", evident in large swathes of common sense, as well as much academic research, regarding the position of the digital computer within our contemporary culture, is misplaced. Pattee's plea is that within computational systems that deal with such generative processes as learning, creativity and intelligence (artificial or otherwise), there is far more frequent

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[111] The reference to 'formal life' in this quote reflects the A-life focus of the essay, but Pattee has used the same von Neumann reference in relation to evolution (Pattee, 1980) and computation (Pattee, 1974).

[112] In light of my assertion that analogue and digital always and only coexist, the 'wholly digital' of this sentence and below must be taken with a caveat: this is an interpretation at a level useful to the conversation, and refers to the fact that the internal, programmable environment of a digital computer is wholly discrete and allows no alternation with continuous processes. It also marks the contrast with the hybrid computational devices of Pask and others, with their frequent alternations between symbolic code and dynamical, concurrent processes.

alternation and interaction between discrete, symbolic, formal modes and continuous, dynamical, time-bound, medium-specific processes. This, he says, is the way that life and biological evolution make use of the tremendous power of code, of formality, while continuing to exploit dynamical, real-time processes that are intimately, inextricably and codependently part of the world in its becoming.

The worlds that Gordon Pask brought forth, throughout his career, answer this plea. From his earliest work with Musicolour, through the electrochemical 'ear', to the many iterations of learning machines, his "deviant" computing systems were hybrid, analogue and digital, often involving asynchronous populations of devices that only locked into local synchronisation through *processes* such as the sharing of information, or the creation of concepts. They happily and readily shuttle back and forth between discrete, formal modes, and continuous, dynamical ones, and we are reminded that Pask did not believe that all of reality could be modelled within a wholly digital environment: "*Process* in general is *not* Turing representable" (Pask, 1979c). He invited us to broaden our conception of computation itself, and his devices constantly questioned the boundaries of individual systems, our place within them, and where control could be said to be manifest. Throughout his career Pask was interested in *concurrent* processes, and although he believed such processes could be formalised – Conversation Theory and its underlying "proto logic" Lp attempted to do exactly this – he did not believe such formality could be adequately instantiated in wholly digital systems. His was a formality of many-valued logic, discrete *and* continuous processes, and above all, of concurrent operations. Pask's formality is anathema to the serial operations and the binary logic of the digital computer. The hybrid systems he built to explore such issues bring about the becoming of coherence, and in such systems it is always impossible to state exactly where *control* is manifest: circularity is the order of the day.

All of this relates very directly to anyone working with music technology today. In this domain the dominance of the digital computer, and a wider, associated computationalism, is evident wherever we see increasing numbers of processes, products and personnel co-opted into an algorithmic setting. This trend is baulked by the stubborn refusal of vinyl, analogue tape, modular synthesis, to quietly

obsolesce. But academic work stoked on the promise of the digital – a faith in its propensity to "ultimately be all" (Norman, 2006, 23, cf. p.119) – tends to dismiss such moves through a periodising logic that posits 'technostalgia', 'hipster' appropriation, the 'post-digital', and a host of other terms that prop up implicit assumptions of historical-technological progression. At the same time this normalises the *currency*[113] of digital devices, approaches, techniques, what have you. In this thesis – through both theoretical discussion and practical exploration – I have tried to show some of the problems with this faith in formality in the music technological domain. I have suggested that the continuing presence of analogue and physical, real world devices and processes is not simply a blip, soon to be subsumed within a digital future. I have tried to show how the narrative of progress at the heart of such beliefs is flawed in important ways. To be sure, contemporary use of tape is nostalgic for some, or a marker of authenticity for others, but I don't believe this is the only way, or indeed the best way, of viewing such actions. I wonder whether the 'blip' is rather the 'detour' that Pickering suggested (cf. p.102): our contemporary culture's bias towards digital devices and computationalism. I wonder also whether the more frequent alternations and interactions between continuous and discrete processes found in 'maverick' computing systems – chemical-, bio-, physical-, reservoir-, evolution-in-materio-, analogue – might soon be seen as vital to AI, A-life, generative systems, evolving systems. At present this looks unlikely, which is one of the reasons for bringing this thesis into being (even though I didn't know that when I began this project).

Research questions revisited

To add further clarity to some of the points above let us revisit the research questions presented in the introduction.

[113] In the sense of the present-day, being "generally accepted or in use" (Oxford English Dictionary, 2018), but also medium of exchange.

Analogue-∂igital

How might a combination of technical, historical and practice-based research, focused through commitment to artistic outputs in the domain of music technology, shed new light on the much used terms analogue and digital, and on the nature of the analogue-digital relationship?

A key contention of this thesis is the idea that *analogue and ∂igital always and only coexist*. This concept has grown with the thesis, and was not what I expected to find when I started this research. This conclusion comes as a result of a detailed and extensive theoretical exploration of both the technical and the changing historical views of these processes, and a thorough practical investigation within realms of music technology deemed obsolete by many, all of which is grounded on extensive music technological 'digital literacy'. These explorations find that there is no single way to define the terms analogue and digital such that it will hold in all circumstances. Attempts to formalise the distinction fall down when trying to move between different domains. What holds for one domain, such as computation, fails to port over to another domain, such as recording, signal, transduction, or what have you. The terms analogue and digital are "substantive-hungry" (cf. p.34), and when attached to a particular noun or noun-phrase definition becomes tractable, but here we see that each term individually needs the other to actually demarcate the distinction: they are complementary, not oppositional. The distinction itself *is* important: it is a difference that makes a difference, but the act of making the distinction is an act of interpretation, and can never be wholly removed from the interests, schemes and biases of an observer who is necessarily participant in the systems thus demarcated. This gives us an ethical responsibility towards the act of interpretation itself: we make a cut because it allows us to gain traction on a situation, but the nature of the cut constrains and conditions further such cuts, and as such we should carry with us a responsibility for this demarcation. The making of the distinction itself is a performative act that brings forth a world. This thesis, then, questions and ultimately refuses commonplace ways of making the cut that privilege either term too greatly. Pronouncements on 'the digital' and related 'digital culture' and 'digital age' vastly overburden the term digital, at the same time as implicitly refusing the complementary importance of the term analogue. Digital is here

asked to do too much work, at the same time as consigning analogue to the position of 'other', as outsider, as inexorably obsolescing past, or as 'everything outside of the computer'. All such pronouncement are refused by this thesis. To posit anything as analogue or digital is to make an interpretation that is useful to the conversation in progress. It is a simplification and an abstraction that allow us to gain some purchase on some complex situation or another. Neither analogue nor digital can be seen as synonymous with the future, or innovation, or the nature of the world, life, or the mind. Let us restore some of the contextual and technical specificity to these terms and thereby allow them to continue to do useful work in a multitude of different domains and disciplines; let us insist upon the multifaceted and complementary nature of their definitions, and be clear about how we are using them and the ramifications of our usage.

These are some of the issues that my practice has explored through *musique concrète*, sound installation, modular synthesis performance, and with special focus on studio recording. I have found a great difference in my practical investigations of what is commonly called 'analogue recording' and 'digital recording'. I have consciously chosen to name this separation 'tape studio' and 'DAW studio', since this names the recording medium at the heart of the production of recorded music, and avoids ambiguity about which bits of the actual recording process are analogue or digital (or both, or neither). I do hold, though, that the most useful way to describe magnetic tape *is* as an analogue medium, just as the DAW is best described as a digital medium. The most important differences in working in these separate domains that I have noted are due to one recording medium being continuous and time-bound, and the other being discrete and time-independent. Surrounding these core recording media are the various complexes of transductions, alternating continuous and discrete processes. The fact of the continuous recording medium of tape is that the music in creation necessarily and inevitably goes through extremely frequent alternations of continuous and discrete processes – these have been enumerated at length in chapters 3 and 6. The fact of the discrete recording medium of the DAW is that the music in creation *may* go through frequent alternations of continuous and discrete, but as we have seen, *tends* to go through far less and *may* go through none at all (other than in the mind of the operator/producer). Pattee has shown how such alternations are

fundamental to life and biological evolution, and suggests that they are also fundamental to issues of creativity, learning and 'higher' cognition. I have certainly come to see all forms of musical creation as a frequent shuttling between discrete, symbolic, time-independent *description* and continuous, performative, time-bound *expression*. My work does not and cannot eschew the coded or the symbolic. It recognises their profound importance, but asks that hybrid processes be given their due, and that the digital computer is not asked to *be* too much.

Progress narratives and succession logic

There is a prevalent assumption that digital music-technological processes represent a progression from preceding analogue processes; how does this assumption stand up to a sustained, committed practice-based exploration?

Central to this thesis's theoretical framework is the idea that digital recorded audio takes sound 'out of time', removing it from the continuous milieu in which it was born (e.g. the transduced analogue signal that outputs the microphone). This discretisation is the hallmark of a terminal, digital transduction (in the A/D converter), and is the key affordance that distinguishes the production environments of the tape studio and the DAW studio. This discretisation affords an unprecedented hyper-mutability, yet music technology discourse tends to posit digital audio editing as an upscaling of the affordances of editing on tape. I suggest, however, that this 'take out of timeness' is *not* a continuation of processes initiated in an 'analogue era'. Instead it is a radical departure from the practices of tape editing which fundamentally reshape the domain of technological musicking. The term 'editing' – apparently innocuous in its functional implications – is co-opted into the succession logic and the assumption of replacement along lines of continuity that I have attempted to identify throughout this thesis. But my embodied engagement with tape editing strongly suggests that digital audio editing is a radical rupture, rather than a continuation. Other elements of recording studio practice, such as musical and technical performance, are also often assumed to port over relatively unchanged from tape studio to DAW (or from tape music composition to the sampler), but my practice-based explorations have highlighted some of the problems with this viewpoint, and how the 'take out

of timeness' of digital audio conditions and regulates studio practices in ways which tend not to have been acknowledged. I have shown how performance is devalued, assuming a lesser significance in general, and in some cases disappearing completely from the process of production. I have indicated how commitment to action, to decision-making, and to performance itself, lessen in the DAW, resulting in a very different sounding music, even when the DAW is pressed into service in emulation of previous (tape-based) styles of production. I have also noted how the embodied, tacit, gestural know-how of the engineer, performer and composer, moving and musicking around the physical space of the tape studio, alter in profound ways with the move to the DAW, and how increasing orders of these embodied processes become rationalised and formalised 'in the box', even if this move is occluded by the multiple skeuomorphic emulations, represented through the "square horizon" of the screen. The unshackling of sound from its temporal milieu allows audio to become so much more code, and affords the encroaching tendency for more and more elements of the traditional tape studio, including increasingly personnel themselves, to be "lumped together" within wholly digital environments. But we recall from Pattee that wholly discrete milieu differ from the processes of life and biological evolution, with their frequent alternation of code and physical interpretation of that code, their alternation of discrete, symbolic *description* and continuous, dynamical *expression*. My musical practice has been a kind of 'de-lumping': forcing alternation by deliberately not lumping all the important parts of the process into one closed environment. Pattee asks whether this complementary interaction of continuous and discrete processes is not essential for higher forms of intellectual behaviour, and I have pursued this question with the commitment that comes from making music that will have its own life in the world at large. I have resisted the *opposition* between analogue and digital, seeing them as complementary. I have noted the many digital processes still in evidence in the various parts of the practice outlined here, even as I stress the importance of the analogue elements. There is no attempt here at 'purity', analogue or otherwise. The practice is resolutely hybrid. All technological musical practices evidence some measure of continuous-discrete, analogue-digital complementarity. Hybridity is the norm, and I believe we should acknowledge and embrace this. Even in the 'purest' digital system there is still a continuous electrical base to the constrained discrete

network; there is still the need for the digital sound to be transduced to analogue sound before transduction to the acoustic sound we can actually listen too; and there is the all important source of both continuous and discrete processes in the mind of the programmer or user of a digital system. We do these rich and important terms, analogue and digital, a very great disservice by writing a progress ridden narrative that runs acoustic to analogue to digital. I believe we should take seriously Pattee's deep insights into the nature of life and evolution, and that we benefit when our musical systems frequently alternate between discrete and continuous modes, especially if we are interested in a music of becoming, a music that allows for under-specified goals such as adaptation and evolution, and that evidence a liveliness that does any justice to life itself.

Exploring the tape studio has pointed up, in no uncertain terms, the necessity and essential underpinning of four related areas: performance, gesture, embodiment and commitment. This has encouraged me to re-evaluate the coded, formal, representational environment of the DAW and to conclude that, for all its vaunted affordances, it tends to devalue, and indeed discourage, all four of these areas. As a composer for whom all of these things are crucial, whose compositional process relies on performance and relishes contingency, who enjoys a craftsman like approach centred on the nexus of mind-hand-ear, who values underspecified goals, wayfinding, laying down a path in walking, all within highly technical environments, then the embrace of what I have here called the tape studio has been something of a revelation: difficult, challenging, frustrating at times, but ultimately conducive to the production of compositions I am happy to let out into the world. I had a hunch that there was a problem with digital audio. I have explored this hunch over the course of several years from a number of different angles. The problem itself is a deeply personal one, and I do not recommend the path I have taken to everyone, but when so much of contemporary culture comes under the rubric of the computational, when the algorithmic becomes dominant, it is easy to assume that that is indeed what musicking should be. I have questioned and ultimately resisted these assumptions in search of a practice that suits the elements of musicking I value – performance, contingency, embodiment, commitment, rich possibilities for evolution – and I have not found the progress

narratives and their attendant succession logic to stand up to my own explorations in these regards.

Cybernetics

How might both practical and theoretical examination of technological musicking be buttressed by the now mostly obscured discipline of cybernetics, in particular the little known cybernetics of Gordon Pask?

This thesis is part of a current resurgence of interest in the obscured field of cybernetics, and I hope I have contributed to this resurgence by showing how Pask's cybernetics can aid us in thinking through and acting around current problems in technological musicking. Of particular relevance and import to this thesis is how second-order cybernetics affords a powerful practical methodology for the examination and creation of dynamical systems in flux, systems that evolve as a result of (participant) interaction, systems that can be seen to manifest self-organisation. Second-order cybernetics puts the emphasis on processes in interaction rather than positing pre-existing objects (including concepts) in a world 'out there'. Cybernetics helps us to explore systems whose complexity and interdependence precludes the separation out into constituent parts, systems where control is shared across multiple mutually interacting dimensions, and where the observer is a committed participant whose actions, interests and biases cannot be divorced from the interactions therein. It is just such systems that I am interested in building within music technological infrastructures, and it is such systems that interest me compositionally.

One of the things noted by many commentators on Pask is how prescient, perspicacious and generally ahead of his time his thinking and making was (for example, Boden (2008), Cariani (1993), Haque (2007), Pickering (2011)). Pask's insistence on buttressing theory through building physical devices – "thought experiments carried out in hardware" (Fuller, 2011, 71) – anticipated contemporary practice-based research by several decades; Musicolour of the early 50s seems, to me, to be unsurpassed as an interaction environment; the 'ear' of the late 50s is still, to this day, the only computational environment that grew its own

"emergent sensory capabilities" (Cariani, 1993, 1). His (and Susan Curran's) 1982 non-technical introduction to computing is extremely unusual in discussing both the history and the yet to be realised promise of *alternatives* to microprocessor-based digital computers. He called these "maverick" computers and commented:

> Maverick designs are quite well documented, but hidden away in conference proceedings or in the archives of funding agencies. One of the purposes of this book is to point out that this intellectual and monetary investment exists and that it should not be forgotten or squandered. People are, from time to time, apt to reinvent the wheel! And reinventions sometimes miss previous clever and crucial ideas, or stumble against obstacles which previous innovators succeeded in solving. (Pask and Curran, 1982, 136)

This is Pask cautioning against progress narratives that assume that the best way to solve a problem is with whatever technology is newest. I have taken such directives seriously in my own historical and practical examinations of music technologies, where the majority of current research happens at what people refer to as 'the cutting edge', which for the last 20 years or so has been almost exclusively synonymous with digital technology.

In relation to the analogue-digital distinction, above, I have highlighted the importance of interpretation, which is central to the drawing of distinctions. The centrality of interpretation, and the inseparability of the observer from the act of interpretation, is key to the second-order cybernetics of Pask and others, and these insights have lost none of their perspicacity, even if cybernetics has become obscured. We have seen how cybernetics, in its earliest incarnation at the Macy conferences dove deep into questions around analogue-digital, particularly in relation to mind, and attempts to mechanise thinking processes. Interpretation, and acknowledging the position of the observer in demarcating a system were central, even if agreement over the nature of analogical and digital processes in body and mind was elusive. Although the tendrils of early AI coiled tightly around this formative cybernetic stem, by the 1960s they had obscured much of the richness of the early growth, promoting an overweening faith in digital (formal, symbolic, representational) processes and eschewing essential notions of complementarity and hybridity. At the same time cybernetics began to be written out of histories of AI and cognitive science (see Boden, 2008). Cariani believes

that this avowed obsolescence was deliberately enforced at multiple points in the history of cybernetics, such as the attempt by Minsky and others to "defund" it, pushing important funding streams into areas such as symbolic AI, and forcing a divergence of disciplines with shared roots in key theoretical work of the 40s and 50s (Cariani, 2017). Cariani commented in the 1990s on what one might be tempted today to call a continuing 'hegemony of digital computation':

> [D]evices such as the digital computer which evolve into large industries create entire worldviews and mold the thinking of the armies of engineers that design, build, manage, and maintain them. Once the digital electronic computer had gained hegemony in information processing, it became difficult if not impossible for large segments of the engineering community to conceive of devices based on radically different design principles. Today anyone attempting to develop such alternatives must contend with the predominance of the digital worldview. (Cariani, 1993, 8-9)

As Maturana and Varela's epigraph, at the top of this chapter, indicates, acts of knowing bring forth worlds, and there has been, for at least the last 30 years, a great deal of 'digital worldbuilding'. Cariani's early 90s quote was prescient: he was talking about 'information processing', but the hegemony of the digital computer has proliferated into a bewildering profusion of areas since then. I believe this hegemony is problematic in all kinds of ways, and my reaction to it certainly informed the bunch of hunches I started this project with, but it is cybernetics, more than anything else, that allowed me to make my own intellectual inroads into the complexity of the situation. Cybernetics has encouraged me in taking a different tack to the historical/technological progress narratives that seem so common and that I also, in many ways, subscribed to before commencing this research.

Attendance at multiple music technology related academic conferences, as well as surveys of the extant literature, not to mention currents in commercial music technology, have convinced me that something very similar to the hegemony Cariani describes is (still) going on with music technology. My engagement with cybernetics has been key to my changed perspective on historical/technological progression, on complex systems, on artificial intelligence and a host of other areas which the domain of music technology both draws from, and feeds into. I join with Pickering, Cariani, Haque and others who hold that cybernetics is not only still

relevant, but that it has explored many important issues with such far sighted perspicacity that it urgently needs to be reconsidered in light of a culture that seems to be becoming more and more computationally oriented. Chapter 3 is my attempt to instate the significance of cybernetics in relation to the domain of the recording studio; and the relationship between cybernetics and the complex performative systems that modular synthesis users build now seems so obvious to me that it seems strange that this connection is still under explored.

On a personal level, there is no doubt that my deep engagement with cybernetics has changed the way that I think, how I see the world, and how I comport myself in that world. Pask's is a performative vision stressing the ethical responsibility we have towards our own engagement with the world in its becoming. Acts of knowing, acts of making, acts of musicking – all bring forth a world. I have taken this seriously in relation to the bringing forth of both musical creation and the environments we value culturally for such creation. Of key import here is the concept of self-organisation and the possibilities for evolution – technical, infrastructural, musical – therein. The environments that allow participant tinkering and creative misuse to aid evolution are the ones I have focused on, and found such opportunities for open ended evolution employing underspecified goals to be prevalent in environments such as the tape studio that encourage frequent alternation and interactions of continuous and discrete processes. Varela calls this "laying down a path in walking" and I have found the path I have laid down through the supposedly obsolete areas such as the tape studio to be conducive to exactly the things that I have always valued in composing and musicking: performance, intuition, surprise, craftsmanship, interdependence of multiple interlocking elements, emergence, complexity, and liveness itself.

Transduction and performativity

How might notions of transduction and performativity help us in explorations of complex technical environments supportive of the embodied production of music?

Although I have spent a quite a large portion of this thesis discussing the continuous and the discrete, this is not the only way to cut apart the domain of

technological musicking. Transduction and performativity both offer fruitful alternatives. But before reviewing this, it is worth remembering that transduction allows us to gain some purchase on the analogue-digital distinction itself, since it allows us to specify, with some degree of rigour, whether final stages in chains of transduction – leading to devices, media, processes, what have you – are continuous or discrete. Thus, I confidently ascribe both magnetic tape and vinyl recording as analogue media, since the final transduction in each case is a continuous one. Likewise, recorded digital audio is the result of a terminal discrete transduction. As we have seen in relation to recording, whether this final stage leads to a continuous, time-bound signal, or to discrete, time-independent code, has important ramifications, not just for what can be done with that signal – its affordances – but for how those affordances condition, regulate and influence the way embodied musicking agents work with that signal.

Transduction is a process at the heart of many music technological operations, and is especially pertinent to the recording studio and recorded music in general, since any recording is the result of multiple chains of transductions, and the essential listening that brings a recording alive is also the result of multiple transductions: the laid down recorded signal (on e.g. magnetic tape, vinyl groove, digital storage) is played back; this signal is transduced to an analogue electronic one, which drives a speaker, wherein the signal is transduced to an acoustic one, which travels through the air to our ears, wherein further transductions occur. Of course there are other examples of this passage from source to ear (e.g. bone conducting headphones, or the signal traveling through water), just as there may be interventions during this passage (the signal might pass through a compressor, or an EQ), all of which will evince further transductions. The point is that transduction is never neutral: just as something is carried over (e.g. a sound) something is changed (e.g. the quality of that sound). Transduction is a process that relates at the same time as it distinguishes.

Further to this, technologies of transduction can constrain performativity at various points and in varying ways. From the pithy telegram to the singing styles of the 'crooners', transduction is never a neutral conduit of information: it constrains and conditions the ways the particular technology is used by active

agents. They may be hoping for clarity in the passage of the message, as in composition of a telegram, or in the 'human microphone' (cf. p.22); or they may consciously exploit unintended side effects, as when the crooners of the 30s discovered both how relatively soft singing close to a microphone suggested intimacy and 'presence' to a listener, and how the proximity effect (itself a side effect of directional microphones) boosted the 'warm' low frequencies of the voice. Frank Sinatra would have been a very different singer had he had to project his unamplified voice into an auditorium. Unwanted side effect can become vaunted affordance as transduction technologies collide with performativity as part of ongoing histories of practice. This co-dependent mutuality between transduction and performativity is one of the things this thesis has attempted to highlight in relation to the complex technical and cultural assemblages of the recording studio, and also in relation to live performance in modular synthesis.

Throughout this thesis I have highlighted the importance of commitment, and have explored it in relation to activities such as recording, where I have found that despite the assumption of isomorphism between analogue and digital recording, levels of commitment vary between the two, recording to tape tending to evince far higher levels of commitment than the 'equivalent' digital recording. I have used this as an argument against the supposed isomorphism, but commitment is also important in and of itself, as noted by Klemmer et al. and others (cf. p.91). Further to this, I relate commitment directly to one of this thesis's key concepts and propose that performativity *is* commitment: not commitment *to* action, but commitment *in* action. Commitment to the bringing about of a world, bringing about the becoming of meaning, of identity. Performativity thus also has an important ethical dimension, highlighted by Barad and Pickering for whom performativity is a useful antidote to representationalism. This performative commitment to the becoming of identity also has parallels with Simondon's notion of *individuation*, and thus also to notions of transduction, which for Simondon is an essential, ongoing, continuous process of differentiation through relation: "Every transduction is an individuation in process. It is a way something comes to be, an ontogenesis" (MacKenzie, 2006, 18).

As a composer, I am interested in unpredictable sounding scenarios, in steering the becoming of sound, negotiating contingency, being part of complex technical environments where interdependency and mutual interaction of multiple elements make it difficult, if not impossible, to state exactly where *control* is manifest, and thereby offer rich potential to surprise me in the moment of musicking. Such environments, such moments of musicking, heighten performativity for me as a musician, and I have especially valued such moments when performativity intersects transduction: this can manifest in the simple twisting of a knob in *The Thing Breathed*, where the complex nested feedback networks, with multiple interacting transductions, make the 'wiggling' knife-edge unpredictable. The commingling of transduction and performativity is also evident in the laying down of a rhythmic bed in the tape pop pieces where my performance influences multiple semi-autonomous interacting clocks; and is especially key to the performance of a mix. The crunch point in the tape studio, in all of this, is the moment of pressing record; this is a pivotal juncture that not only initiates the transduction that lays the signal down on tape, but also transduces between the pre-recording rehearsal, setup, calibration, fixing in memory, preparing readiness stage, and the performative recording stage itself, which *commits* to tape. I have indicated how much harder it is to find such a pivotal juncture when recording to the DAW, where the performer is almost always aware of the affordances of post-performance editing, and so offloads much of their own commitment to performance to a later time, or to other people. I am not setting up this opposition in order to claim higher value for one or the other, rather to indicate that for me, as a composing musician who values performance, and who makes music in which a presentation of performance is important, the tape studio *works*, in ways which I have always found problematic in the DAW.[114]

[114] While acknowledging that language use can itself be problematic: what 'works' for me might appear as a wilfully contrary refusal to move with the times by others. And much of the discussion around the 'democratisation' of the studio, said to accompany introduction of the DAW, revolves around making technologically complex studio environments 'work' for growing numbers of 'amateur' producers. Again, the position outlined here is a personal one – I do not claim generality in 'what works', rather encourage fitting means of production to one's own predilections.

Original contribution to knowledge

> Let my pattern of inevitably incomplete competence cover areas neglected by others. (Campbell, 1969, 15)
>
> Another lesson we continually relearn is that originality is something of a snare if not a positive delusion. (Pask, 1976, 76)

The work discussed here is resolutely interdisciplinary, and the intersections herein, the knotting together of diverse realities and domains, is, I maintain, an original contribution to the theory and practice of technological musicking.

One contribution highlighted here is that insights wrought from physical engagement with material practices are different to those that come either from surveying the literature of a domain, or from the attempt to simulate within a different domain. The insight itself may not be new, but the confirmation through practice discussed here is, I believe, a significant contribution to the buttressing of this conclusion.

The practice itself is original, even if the techniques and technologies used are not innovative or 'cutting edge', as commonly defined. These pieces are my own compositions, and I have made technology both substance and subject of these compositions.

The cybernetics of the studio of chapter 3 presents a novel way of exploring, through a Paskian cybernetic methodology, recording studio dynamics involving the intersection of: technological infrastructure; transduction; participant interaction; embodiment, gesture and performativity; self-organisation; and possibilities for evolution.

The long exploration of analogue and digital in chapter 2 presents much that surveys existing work. The conclusions, detailed in that chapter and immediately above, are my own, and are, to a certain extent, original in that they present an unorthodox perspective.

Practice-based research into popular music production is, at present, under explored; chapter 6 presents a significant contribution to this area.

Directions for future research

Many threads have been left dangling in order to prune growth of the thesis, some of which are presented below with incipient anticipation of continuation.

Tensegrity

Some initial practice-based research was carried out into this area which led to an installation at Sussex in 2016. Tensegrity is a structural form invented by sculptor Kenneth Snelson, and named and articulated more famously by Buckminster Fuller in the 1960s. There has been a concerted exploration of this area in the last ten years in architecture, but also interest from the fields of robotics, reservoir computing and other areas germane to the concerns expressed here. Fuller used tensegrity as exemplar of the complementarity of compression and tension (they "always and only coexist"), but it is also of direct relevance to my practice through its intimate, complementary weaving together of continuous (the tension wires) and discrete (the struts). It is also germane to currents in Pask's late work yet to be built upon by scholars: Pask was experimenting with the form in the early 90s as "elements of a potential concurrent computer" (Green, 2004, 1436), indicating his continued interest in maverick, unconventional forms of computation. I will continue to explore this structural form in connection with modular synthesis, the self-organising studio and other areas.

Further work on the self-organising studio

With continued attention to the frequent alternation of discrete-continuous. There is certainly an article to be written on the self-organising studios of Prince, Kate Bush, Laurie Anderson, Lee Perry, Todd Rundgren, and others.

A theory of cybernetic musicking

This thesis is the first act: it has, in walking, laid down the first few steps, and, in growing itself, constrained the eventual theory, as any evolving framework must.

Much work still to be done on evolution

I have indicated, in 'The life and evolution of a song' (cf. p.51) how Pattee's theories of cell physiology and biological evolution could be applied to ideas of evolution in music. There is much here that could be developed.

Ranulph Glanville

An experimental electronic musician turned cybernetician via doctoral study with Pask. His work is under explored in music scholarship, and I have only been able to touch on him in this thesis. His article on his own music (Glanville, 2001c) is important both to his status as an unsung 60s electronic music innovator and to connections between music and cybernetics. There are a rich set of interconnections with Pask, Allan Strange, listening, design and much else. I have no doubt he grew cybernetic ears.

Growing cybernetic ears

> …this work has grown itself, and I have, to the best of my ability, notated it. (Glanville, 1975, iii)

I have indicated at various points how my own thinking has changed through the course of this PhD. This is why I talk of 'growing a thesis', in line with Glanville's comment on his own PhD thesis, above, and why 'growing cybernetic ears' is a process that is ongoing, a constant becoming. This is pursuit of Pask's underspecified goals. I did not start with preconceived ideas of what I would achieve, I followed a path in walking that led me to here, as it led me to hear.

But…

I tire of talk.

> When I talk, I cannot guarantee that anyone listens. I can hope they do. But the response I may be looking for is not within my gift: it is in the gift of the listener. To listen is to connect and to participate. To listen is to sign on. (Glanville, 2001c, 4)

Growing cybernetic ears is…

Constantly adapting our listening to a changing world.

Taking seriously the part we play in the coevolution of humans and machines in the domain of technological musicking.

Encouraging the machines we coevolve with to be more compelling conversational partners, and the technological environments we inhabit to foster better interaction through better listening.

An interdisciplinary approach: listening outside one's own field for cross-currents of relevance.
A historical approach: listening to the past with ears pricked for resonances germane to research and practice.
A technological approach: listening both to the sounds we make with our machines, and to the manner in which they encourage and regulate musicking.

A most becoming process.

Bibliography

Analytical Engine, 2017. Wikipedia.
Auner, J., 2003. "Sing It for Me": Posthuman Ventriloquism in Recent Popular Music. J. R. Music. Assoc. 128, 98–122.
Austin, J.L., 1979. Sense and Sensibilia, 2Rev Ed edition. ed. OUP USA, London.
Barad, K., 2003. Posthumanist Performativity: Toward an Understanding of How Matter Comes to Matter. Signs J. Women Cult. Soc. 28, 801–831. https://doi.org/10.1086/345321
Barad, K.M., 2007. Meeting the Universe Halfway: Quantum Physics and the Entanglement of Matter and Meaning. Duke University Press, Durham.
Bate, M., 2006. What the Future Sounded Like [documentary]. Porthmeor Productions, Australia.
Bates, E., 2009. Ron's Right Arm: Tactility, Visualization, and the Synesthesia Of Audio Engineering. J. Art Rec. Prod. 4.
Bateson, G., 2000. Steps to an Ecology of Mind, ed. University of Chicago Press, Chicago.
Beatty, C., 2007. "We'll Fix It in the Mix": The Era of Unlimited Tracks [video interview]. URL https://www.youtube.com/watch?v=7LDneHRhP-o
Beer, S., 2001. A Filigree Friendship. Kybernetes 30, 551–560. https://doi.org/10.1108/03684920110391779
Bell, A., Hein, E., Ratcliffe, J., 2015. Beyond Skeuomorphism: The Evolution of Music Production Software User Interface Metaphors. J. Art Rec. Prod. 9.
Bennett, S., 2012. Endless Analogue: Situating Vintage Technologies in the Contemporary Recording & Production Workplace. J. Art Rec. Prod. 7.
Bird, J., Di Paolo, E., 2008. Gordon Pask and His Maverick Machines.
Bird, J., Layzell, P., Webster, A., Husbands, P., 2003. Towards Epistemically Autonomous Robots: Exploiting the Potential of Physical Systems. Leonardo 36, 109–114. https://doi.org/10.1162/002409403321554161
Blake, K., 2009. The Delian Mode [documentary]. Canada.
Boden, M., 2008. Mind as Machine: A History of Cognitive Science. OUP Oxford, Oxford; New York.
Born, G., 1995. Rationalizing Culture: IRCAM, Boulez, and the Institutionalization of the Musical Avant-Garde. Univ. of California Press, Berkeley, Calif.
Botstein, S., 2014. The Distillery Episode #1: Road Trip with "MUFFWIGGLER" MIKE MCGRATH (Part II) — Sam Botstein [WWW Document]. URL http://sambotstein.com/distillery/2014/6/24/the-distillery-episode-1-road-trip-with-muffwiggler-mike-mcgrath-part-ii (accessed 3.25.15).
Brand, S. 1987. Media Lab: Inventing the Future at MIT. Penguin Books, New York.
Buckley, J., 2011. Believing in the (Analogico-)Digital. Cult. Mach. 12.
Burgess, R.J., 2013. The Art of Music Production: the Theory and Practice.
Caluwaerts, K., D'Haene, M., Verstraeten, D., Schrauwen, B., 2013. Locomotion Without a Brain: Physical Reservoir Computing in Tensegrity Structures. Artif. Life 19, 35–66. https://doi.org/10.1162/ARTL_a_00080

Campbell, D., 1969. Ethnocentrism of Disciplines and the Fish-Scale Model of Omniscience.
Campbell, D., 1960. Blind Variation and Selective Survival as a General Strategy in Knowledge-Processes, in: Self-Organizing Systems: Proceedings of an Interdisciplinary Conference. Pergamon Press.
Candy, L., Edmonds, E., 2010. The Role of the Artefact and Frameworks for Practice-based Research, in: The Routledge Companion to Research in the Arts. Routledge.
Cariani, P., 2017. The Passage of a Transdisciplinary Movement through an All-Too-Brief Moment in Time. Review of The Cybernetics Moment: or Why We Call Our Age the Information Age, Ronald R. Kline. Johns Hopkins (2015). Cogn. Syst. Res. 43, 119–124.
Cariani, P., 1993. To Evolve an Ear. Epistemological Implications of Gordon Pask's Electrochemical Devices. Syst. Res. 10, 19–33.
Cariani, P., 1991. Adaptivity and Emergence in Organisms and Devices. World Futur. 32, 111–132. https://doi.org/10.1080/02604027.1991.9972254
Centrifugal governor, 2017. Wikipedia.
Collins, N., 2011. "Pea Soup" - A History.
Collins, N., 2002. All This and Brains Too: Thirty Years of Howling Round. Reson. Mag. 9.
Cramer, F., 2015. What is 'Post-digital'?, in: Berry, D.M., Dieter, M. (Eds.), Postdigital Aesthetics. Palgrave Macmillan UK, London, pp. 12–26. https://doi.org/10.1057/9781137437204_2
Cusick, S., 2017. Musicology, Performativity, Acoustemology, in: Theorizing Sound Writing. Wesleyan University Press.
Cybernetics, 2018. Wikipedia.
Cybernetics, 2017. Wikipedia.
De Man, B., Riess, J., 2013. A Semantic Approach to Autonomous Mixing. J. Art Rec. Prod. 8.
Di Scipio, A., 2003. Sound is the Interface: From Interactive to Ecosystemic Signal Processing. Organised Sound 8, 269–277. https://doi.org/10.1017/S1355771803000244
Dickinson, K., 2001. "Believe"? Vocoders, Digitalised Female Identity and Camp. Pop. Music 20, 333–347.
Difference engine, 2017. Wikipedia.
Duigan, M., Noble, J., Biddle, R., 2010. Abstraction and Activity in Computer-Mediated Music Production. Comput. Music J. 34.4, 22–33.
Dunbar-Hester, C., 2010. Listening to Cybernetics: Music, Machines, and Nervous Systems, 1950-1980. Sci. Technol. Hum. Values 35, 113–139. https://doi.org/10.1177/0162243909337116
Dupuy, J.-P., 2009. On the Origins of Cognitive Science: the Mechanization of the Mind, A Bradford book. MIT Press, Cambridge, Mass.
Emmerson, S., 2007. Living Electronic Music. Ashgate, Aldershot, Hants, England ; Burlington, VT.
Fischer, T., 2011. When is Analog? When is Digital? Kybernetes 40, 1004–1014. https://doi.org/10.1108/03684921111160232
Fuller, M., 2011. FCJ-118 Faulty Theory. Fibreculture J. 69–81.
Fuller, R.B., 1970. I Seem to Be a Verb. Bantam.

Fuller, R.B., Applewhite, E.J., Loeb, A.L., 1982. Synergetics: Explorations in the Geometry of Thinking, New edition edition. ed. Prentice Hall & IBD, New York.

Gaver, B., 2002. Designeing For Homo Ludens. 13 Mag.

Gerard, R., 2016. Some of the Problems Concerning Digital Notions in the Central Nervous System, in: Cybernetics. The Macy Conferences 1946-1953. The Complete Transactions. University of Chicago Press, Chicago, Ill.

Glanville, R., 2004. The Purpose of Second-order Cybernetics. Kybernetes 33, 1379–1386. https://doi.org/10.1108/03684920410556016

Glanville, R., 2001a. And He was Magic. Kybernetes 30, 652–673. https://doi.org/10.1108/03684920110391904

Glanville, R., 2001b. Listen!, in: Problems of Participation and Connection. pp. 425–432.

Glanville, R., 2001c. Between Now and Then: The Auto-Interview of a Lapsed Musician. Leonardo Music J. 35–42. https://doi.org/10.1162/096112101527806 56

Glanville, R., 1975. A Cybernetic Development of Epistemology and Observation, Applied to Objects in Space and Time (as Seen in Architecture) (PhD). Brunel University, Uxbridge.

Goodman, N., 1976. Languages of Art: An Approach to a Theory of Symbols, 2. ed., [Nachdr.]. ed. Hackett, Indianapolis, Ind.

Gould, G., 2004. The Prospects of Recording, in: Audio Culture: Readings in Modern Music. Bloomsbury.

Green, N., 2004. Axioms from Interactions of Actors Theory. Kybernetes 33, 1433–1462. https://doi.org/10.1108/03684920410556070

Green, N., 2001. On Gordon Pask. Kybernetes 30, 673–682. https://doi.org/10.1108/03684920110391913

Hacking, I., 1983. Representing and Intervening: Introductory Topics in the Philosophy of Natural Science. Cambridge University Press, Cambridge; New York.

Halzack, S., 2016. The Big Business Behind the Adult Coloring Book Craze [WWW Document]. Wash. Post. URL https://www.washingtonpost.com/business/economy/the-big-business-behind-the-adult-coloring-book-craze/2016/03/09/ccf241bc-da62-11e5-891a-4ed04f4213e8_story.html (accessed 7.10.18).

Haque, U., 2007. The Architectural Relevance of Gordon Pask. Archit. Des. 77, 54–61. https://doi.org/10.1002/ad.487

Haugeland, J., 1996. Body and World: A Review of What Computers Still Can't Do: A Critique of Artificial Reason (Hubert L. Dreyfus). Artif. Intell. 80, 119–128. https://doi.org/10.1016/0004-3702(95)00084-4

Haugeland, J., 1981. Analog and Analog. Philos. Top. 12, 213–225. https://doi.org/10.5840/philtopics198112150

Hayles, K., 1999. How We Became Posthuman: Virtual Bodies in Cybernetics, Literature, and Informatics, 74th edition. ed. University of Chicago Press, Chicago, Ill.

Helmreich, S., McMurray, P., 2017. Tape, Prince, and the Studio: Interview with Susan Rogers 23 May 2016, Cambridge, MA. Twent.-Century Music 14, 135–147. https://doi.org/10.1017/S1478572217000111

Hogg, B., Norman, S.J., 2013. Resistant Materials in Musical Creativity. Contemp. Music Rev. 32, 115–118. https://doi.org/10.1080/07494467.2013.775804
Holopainen, R., 2012. Self-organised Sound with Autonomous Instruments: Aesthetics and Experiments.
Irvin, J., 2007. The Mojo Collection: 4th Edition: The Ultimate Music Companion, Main edition. ed. Canongate Books, Edinburgh.
Junior Electronics, 2012. Musostics. Bureau B.
Junior Electronics, 2007. Junior Electronics. Duophonic Super 45s.
Keane, D., 1981. Tape Music Composition. Oxford University Press, London usw.
Kehew, K.R.& B., 2006. Recording the Beatles : The Studio Equipment and Techniques Used to Create Their Classic Albums, 1st edition. ed. Curvebender Publishing, Houston, Tex.
Kirby, P., 2015. The Evolution and Decline of the Traditional Recording Studio (PhD). University of Liverpool.
Kirsh, D., Maglio, P., 1994. On Distinguishing Epistemic from Pragmatic Action. Cogn. Sci. 18, 513–549. https://doi.org/10.1207/s15516709cog1804_1
Klemmer, S., Hartmann, B., Takayama, L., 2006. How Bodies Matter: Five Themes for Interaction Design, in: DIS '06 Proceedings of the 6th Conference on Designing Interactive Systems. pp. 140–149.
Knowles, J., Hewitt, D., 2012. Performance Recordivity: Studio Music in a Live Context. J. Art Rec. Prod. 6.
Leider, C., 2004. Digital Audio Workstation. McGraw-Hill, New York.
MacKenzie, A., 2006. Transductions: Bodies and Machines at Speed. A&C Black.
MacKenzie, A., 2003. Transduction: Invention, Innovation and Collective Life.
Massumi, B., 2002. Parables for the Virtual: Movement, Affect, Sensation, Post-Contemporary Interventions. Duke University Press, Durham, NC.
Maturana, H., Varela, F.J., 1992. The Tree of Knowledge: The Biological Roots of Human Understanding, 3rd Revised edition edition. ed. Shambhala Publications Inc, Boston : New York.
McCulloch, W., Pitts, W., 1945. A Logical Calculus of the Ideas Immanent in Nervous Activity. Bull. Math. Biophys. 5.
McIntyre, P., 2015. Tradition and Innovation in Creative Studio Practice: The Use of Older Gear, Processes and Ideas in Conjunction With Digital Technologies. J. Art Rec. Prod. 9.
Miller, J.F., Harding, S.L., Tufte, G., 2014. Evolution-in-materio: Evolving Computation in Materials. Evol. Intell. 7, 49–67. https://doi.org/10.1007/s12065-014-0106-6
Mourjopoulos, J., 2005. The Evolution of Digital Audio Technology. Communication Acoustics, in: Communication Acoustics. Springer, pp. 299–319.
Nakai, Y., 2014. Hear After: Matters of Life and Death in David Tudor's Electronic Music. https://doi.org/10.7275/R5GT5K3F
Nelson, T.H., 1987. Computer Lib ; Dream Machines, Rev. ed. ed. Tempus Books of Microsoft Press, Redmond, Wash.
Norman, S.J., 2018. Tuning and Metagesture After New Natures, in: Emmerson, S. (Ed.), The Routledge Research Companion to Electronic Music: Reaching out with Technology. Routledge.

Norman, S.J., 2006. Generic Versus Idiosyncratic Expression in Live Performance Using Digital Tools. Perform. Res. 11, 23–29. https://doi.org/10.1080/13528160701363259
Oliveros, P., 1984. Software for People Collected Writings 1963-80. Writers & Books, Baltimore, Md.; Barrytown, N.Y.
Pangaro, P., 1987. An Examination and Confirmation of a Macro Theory of Conversations through A Realization of the Protologic Lp by Microscopic Simulation (PhD). Brunel University, London.
Pask, G., 1992a. Different Kinds of Cybernetics, in: New Perspectives on Cybernetics: Self-Organization, Autonomy and Connectionism. Kluwer, Dordrecht, pp. 11–31.
Pask, G., 1992b. Interaction of Actors, Theory and Some Applications: Volume 1, Outline and Overview.
Pask, G., 1987. Conversation and Support.
Pask, G., 1980. Developments in Conversation Theory—Part 1. Int. J. Man-Mach. Stud. 13, 357–411. https://doi.org/10.1016/S0020-7373(80)80002-2
Pask, G., 1979a. Consciousness. J. Cybern. 9, 211–258.
Pask, G., 1979b. An Essay on the Kinetics of Language, Behaviour and Thought, in: Proceedings of the Silver Anniversary Meeting of the Society for General Systems Research. pp. 111–128.
Pask, G., 1979c. A Broader View of Psychology and of Computation. Behav. Brain Sci. 2, 486.
Pask, G., 1976. Conversation Theory: Applications in Education and Epistemology. Elsevier Science Ltd, Amsterdam ; New York.
Pask, G., 1975a. Cybernetics of Human Learning and Performance, First Edition edition. ed. Hutchinson, London.
Pask, G., 1975b. Conversation, Cognition and Learning: Cybernetic Theory and Methodology. Elsevier Science Ltd, Amsterdam.
Pask, G., 1971. A Comment, a Case History and a Plan. Cybern. Art Ideas 76–99.
Pask, G., 1969. The Architectural Relevance of Cybernetics. Archit. Des. 9, 494–496.
Pask, G., 1964. A Discussion of Artificial Intelligence and Self-Organization, in: Advances in Computers. Elsevier, pp. 109–226. https://doi.org/10.1016/S0065-2458(08)60353-8
Pask, G., 1961. An Approach to Cybernetics. Hutchinson.
Pask, G., 1959. The Natural History of Networks, in: Proceedings of International Tracts In Computer Science and Technology and Their Application. pp. 232–263.
Pask, G., Curran, S., 1982. Micro Man. MacMillan Publishing Company, New York.
Pattee, H., 2015. Cell Phenomenology: The First Phenomenon. Prog. Biophys. Mol. Biol. 119, 461–468. https://doi.org/10.1016/j.pbiomolbio.2015.06.010
Pattee, H., 1995. Artificial Life Needs a Real Epistemology, in: Advances in Artificial Life. Springer-Verlag, Berlin.
Pattee, H., 1993. The Limitations of Formal Models of Measurement, Control, and Cognition. Appl. Math. Comput. 56, 111–130. https://doi.org/10.1016/0096-3003(93)90118-X
Pattee, H., 1980. Universal Principles of Measurement and Language Functions in Evolving Systems, in: Casti, J., Karlqvist, A. (Eds.), Complexity,

Language, and Life: Mathematical Approaches. Springer-Verlag, Berlin, pp. 268–281.
Pattee, H., 1974. Discrete and Continuous Processes in Computers and Brains, in: Physics and Mathematics of the Nervous System. Springer, Berline, pp. 128–148.
Pattee, H., Kull, K., 2009. A Biosemiotic Conversation: Between Physics and Semiotics. Sign Syst. Stud. 37, 311–331.
Penny, S., 2013. Art and Robotics: Sixty Years of Situated Machines. AI Soc. 28, 147–156. https://doi.org/10.1007/s00146-012-0404-4
Penrose, S.R., 1999. The Emperor's New Mind: Concerning Computers, Minds, and the Laws of Physics, New Ed edition. ed. OUP Oxford, Oxford.
Peters, B. (Ed.), 2016. Digital Keywords: A Vocabulary of Information Society and Culture, Princeton Studies in Culture and Technology. Princeton University Press, Princeton.
Pias, C., 2005. Analog, Digital, and the Cybernetic Illusion. Kybernetes 34, 543–550. https://doi.org/10.1108/03684920510581710
Pickering, A., 2011. The Cybernetic Brain: Sketches of Another Future. University of Chicago Press, Chicago; London.
Pickering, A., 2009. Beyond Design: Cybernetics, Biological Computers and Hylozoism. Synthese 168, 469–491. https://doi.org/10.1007/s11229-008-9446-z
Pickering, A., 2007. Ontological Theatre Gordon Pask, Cybernetics, and the Arts. Cybern. Hum. Knowing 14, 43–57.
Rabardel, P., 2002. People and Technology.
Rodgers, T., 2015. Tinkering with Cultural Memory: Gender and the Politics of Synthesizer Historiography. Fem. Media Hist. 1, 5–30. https://doi.org/10.1525/fmh.2015.1.4.5
Rodgers, T., 2010a. Pink Noises : Women on Electronic Music and Sound. Duke University Press ; Chesham, Durham, NC.
Rodgers, T., 2010b. Synthesizing Sound: Metaphor in Audio-Technical Discourse and Synthesis History (PhD). McGill University, Montreal.
Rotman, B., 2008. Becoming Beside Ourselves: The Alphabet, Ghosts, and Distributed Human Being. Duke University Press, Durham.
Rylan, J., 2008. Little Boy Blue Manual & Tutorial.
Rylan, J., 2006. Little Boy Blue Manual (2006).
Savage, S., 2011. Bytes and Backbeats: Repurposing Music in the Digital Age, Tracking Pop. University of Michigan Press, Ann Arbor, Mich.
Schonbein, W., 2014. Varieties of Analog and Digital Representation. Minds Mach. 24, 415–438. https://doi.org/10.1007/s11023-014-9342-x
Schwab, M. (Ed.), 2016. Experimental Systems. Future Knowledge in Artistic Research, Adapted edition edition. ed. Leuven University Press, Leuven (Belgium).
Scott, B., 2001. Gordon Pask's Conversation Theory: A Domain Independent Constructivist Model of Human Knowing. Found. Sci. 6, 343–360.
Scott, B., 1982. The Cybernetics of Gordon Pask, Part 2. Int. Cybern. Newsl.
Sennett, R., 2008. The Craftsman. Allen Lane, London.
Simondon, G., 2016. On the Mode of Existence of Technical Objects. Univocal Pub, Minneapolis, MN.
Small, C., 1998. Musicking: The Meanings of Performing and Listening, Music/Culture. University Press of New England, Hanover.

Spencer-Brown, G. 1997. Gesetze der Form. Bohmeier Verlag, Lübeck.
Sterne, J., 2016. Analog, in: Digital Keywords: A Vocabulary of Information Society and Culture. Princeton University Press, Princeton, pp. 31–44.
Sterne, J., 2007. Out With the Trash: On the Future of New Technologies, in: Residual Media. University of Minnesota Press, Minneapolis, pp. 16–31.
Sterne, J., 2006. The Death and Life of Digital Audio. Interdiscip. Sci. Rev. 31, 338–348. https://doi.org/10.1179/030801806X143277
Sterne, J., 2003. The Audible Past: Cultural Origins of Sound Reproduction. Duke University Press, Durham.
Sterne, J., Rodgers, T., 2011. The Poetics of Signal Processing. differences 22, 31–53. https://doi.org/10.1215/10407391-1428834
Strachan, R., 2017. Sonic Technologies: Popular Music, Digital Culture and the Creative Process. Bloomsbury Academic, New York, NY.
Strange, A., 1982. Electronic Music: Systems, Techniques and Controls, 2nd Revised edition edition. ed. McGraw-Hill Inc.,US, Dubuque, Iowa.
Strange, A., 1972. Electronic Music: Systems, Techniques and Controls, 1st edition. ed. Wm.C.Brown.
Teruggi, D., 2007. Technology and Musique Concrète: The Technical Developments of the Groupe de Recherches Musicales and their Implication in Musical Composition. Organised Sound 12. https://doi.org/10.1017/S1355771807001914
Théberge, P., 2015. Digitalization, in: The Routledge Reader on the Sociology of Music. Routledge.
Thompson, A., Layzell, P., 1999. Analysis of Unconventional Evolved Electronics. Commun. ACM 42, 71–79. https://doi.org/10.1145/299157.299174
Tingen, P., 2004. Autechre [WWW Document]. URL https://www.soundonsound.com/people/autechre (accessed 7.13.18).
Toop, D., 1995. Ocean of Sound: Aether Talk, Ambient Sound and Imaginary Worlds [WWW Document]. URL https://www.amazon.co.uk/Ocean-Sound-Aether-Ambient-Imaginary/dp/1852427434 (accessed 9.3.17).
Varela, F., 1997. Patterns of life: Intertwining identity and cognition. Brain Cogn. 34, 72–87.
Varela, F.J., 1986. Laying Down a Path in Walking. Cybernetic 2, 84.
Varela, F.J., Rosch, E., Thompson, E., 1993. The Embodied Mind: Cognitive Science and Human Experience, New edition edition. ed. MIT Press, Cambridge, Mass.
Veal, M., 2007. Dub: Soundscapes and Shattered Songs in Jamaican Reggae, Annotated Edition edition. ed. Wesleyan University Press, Middletown, CT.
Virilio, P., 1997. Open sky. Verso, London ; New York.
von Neumann, J., 1966. Theory of Self-Reproducing Automata. University of Illinois Press, Champaign, IL, USA.
Wiener, 1961. Cybernetics: or Control and Communication in the Animal and the Machine, second edition edition. ed. MIT Press, Cambridge, Mass.
Williams, A., 2015. Technostalgia and the Cry of the Lonely Recordist. J. Art Rec. Prod. 9.
Williams, A., 2012. Putting it on Display: The Impact of Visual Information on Control Room Dynamics. J. Art Rec. Prod. 6.
Winograd, T., Flores, F., 1987. Understanding Computers and Cognition: A New Foundation for Design, New Ed edition. ed. Addison Wesley, Boston.

APPENDIX 1: GLOSSARY OF TECHNICAL TERMS

- A/D converter: transducer that converts an analogue signal into a digital signal
- Arpeggiator: function found on various synthesisers that plays back a held chord as a spread arpeggio, clocked in various ways, usually by an onboard LFO
- Bounce: process of recording one or more tape track to another tape track on the same machine. An essential process with an 8-track recorder if there are more than 8 things to record. The term is also used in DAWs to indicate an 'in the box' mix, or other process that combines multiple digital audio files into a single one
- Brickwall limiting: extreme form of compression that uses a digital algorithm that presents a 'brickwall' ceiling, beyond which no signal can pass. It has been used to make digital mixes louder and louder (the 'loudness war'), though that trend seems now to be on the wane
- Clock divider: modular synthesis element that takes in a clock signal and outputs various 'divided by' outputs. E.g. a /2 output would give a half-time clock signal
- Comping: compilation of various takes of a performance into one definitive take. Standard practice in a DAW. Possible on tape, but depends on how many tracks are free, and involves internal bouncing which degrades the quality of the sound
- Compressor: signal processing device that reduces dynamic range
- CV: Control Voltage – modular synthesis term applied to non-audio signals used to control parameters of modules. E.g. an oscillator will have a CV input that would allow another module, such as an LFO, to control the pitch of the oscillator
- D/A converter: transducer that converts a digital signal into an analogue signal
- DAW: Digital Audio Workstation – piece of software that allows a computer to deal with digital audio, recording, editing, MIDI, etc., all in

one production environment. Standard equipment for most audio production since the mid-2000s

- Drop-in: process of recording a new section into an existing recording on tape. Used to fix errors of performance, etc. There has to be enough time both before and after the drop-in for this to operate successfully
- EQ: equalisation – signal processing device that alters the frequency content of an audio signal
- Fader: linear potentiometer found on mixing desks. The primary way of setting the level of a channel on the mixing desk
- Fader riding: moving the fader in live performance of a mix or other recording, allowing changes of level to certain elements of the mix
- 'In the box': term used in DAW mixing to indicate that all summing of audio, signal processing and addition of effects happens within the software environment. Contrasted to an 'out of the box' mix which would include hardware such as a mixer (to sum audio and set levels), compressors and EQ for signal processing, and outboard effects such as reverb and delay
- LFO: Low Frequency Oscillator – synthesis term for a device that outputs an oscillating signal with a frequency below that of audio (below 20Hz). Generally used as a control device to 'wobble' parameters such as pitch (vibrato) or volume (tremelo)
- MIDI: Musical Instrument Digital Interface – communications protocol established in the early 1980s to allow different musical devices to exchange control information
- Multitrack (tape, etc.): tape or tape machine that has multiple tracks that can be recorded onto. All of the multitrack work in this thesis uses an 8-track multitrack
- Oscillator: synthesis term for the device which produces the primary audio signal
- Physical modelling: digital synthesis technique which formalises in code aspects of the behaviour of physical instruments (acoustic or electronic), allowing digital emulation of those instruments

- Plug-in: digital device used in a DAW that (usually) emulates the behaviour of hardware signal processors and effects such as compressors, EQ, reverb, etc.
- Preamp: analogue electronic device that boosts the very low output of a microphone to a level that is usable by other devices (signal processors, mixers, tape machines, A/D converters, etc.)
- Pulse wave: one of the common waveforms of synthesiser oscillators. An on/off oscillation that buzzes at audio frequencies and can also be used as a clock signal
- Quantise: digital process used in both A/D conversion and in MIDI editing. Places events (e.g. volume of an audio signal or a MIDI event) onto a discrete grid
- Sampling: digital process describing how an A/D converter slices up incoming analogue audio into discrete segments (each of which is further quantised for level). Also commonly used to refer to the practice of using digital audio in a dedicated piece of hardware called a sampler, or using a DAW like a sampler (e.g. by sampling the music of another artist)
- Sound on sound recording: layering of one recording on top of another
- Tape head: transducer that converts an analogue electronic signal into a continuous magnetic flux that can be recorded onto magnetic tape, or allows playback of magnetic tape by reversing the process
- Tape splicing: process of cutting and joining together sections of analogue tape
- Tracking: the term for recording in the studio. Contrasted with 'mixing', which happens after tracking. The term comes from the practice of layering separate recordings onto a multitrack

APPENDIX 2: DOCUMENTATION

All documentation for the practice is presented on this website: http://euterprise.com

The PhD documentation is under 'music research': http://euterprise.com/index.php/music-research/, which is divided up into the following four sections:

1. Tape music composition work (chapter 4): http://euterprise.com/index.php/music-research/musique-concrete/

2. Tape sound installations (chapter 4): http://euterprise.com/index.php/music-research/sound-installations/

3. Modular synthesis (chapter 5): http://euterprise.com/index.php/music-research/modular-synthesis/

4. Tape pop production, the Euterprise EP (chapter 6): http://euterprise.com/index.php/music-research/euterprise-ep/
This section is the most detailed, and gives complete documentation of the entire production process of each of the four tracks, giving significant additional contextual information:
Letter Game: http://euterprise.com/index.php/music-research/euterprise-ep/letter-game/
Perfect Man: http://euterprise.com/index.php/music-research/euterprise-ep/perfect-man/
Vinyl Coffin: http://euterprise.com/index.php/music-research/euterprise-ep/vinyl-coffin/
Substantive-Hungry Trouser-Word: http://euterprise.com/index.php/music-research/euterprise-ep/substantive-hungry-trouser-word/

I have linked to specific pages on the website throughout the thesis.

APPENDIX 3: EUTERPRISE EP – THE RECORD

The 45rpm 12" EP that comes in the submission package has been cut specifically for the PhD submission (3 copies) for examiners to listen to. It was cut by Jonathan Harris Cowley at Cutting Grooves, using a modified record deck built in Germany (see http://www.cuttinggrooves.co.uk/index.html). What is produced is not the same as a commercially released pressing of a record. For that process an initial lacquer is cut in the mastering room, which is then sent to a vinyl pressing plant which will press the records for mass distribution from the lacquer. The system Jonathan uses creates 'endless dubplates' (also called 'one-off vinyl', 'vinyl carving', etc.): one-off cuts that can be played many times (unlike traditional dubplates that wear out after a few plays). The record was cut directly from the mix tapes that I made (and that you can hear digitised versions of on the website). This process happened only just before I submitted the PhD, and so has not been reflected on in the thesis. The process was not straightforward, and I actually had to go back to get the three records cut a second time, since the first batch were unplayable due to very loud bass masking all of the high frequency detail. As it is, the record does sound different to the mix tape – in particular the stereo imaging has suffered due to the limitations of the system. I do fully intend to have this record pressed in the conventional manner later (in full stereo), in conjunction with the record label Bureau B (http://www.bureau-b.com/juniorelectronics.php), but details of this are yet to be finalised as I write this. I am still happy with the sound of the record included here, and it was important that there was a physical product at the end of the process.

The cutting process is documented at: http://euterprise.com/index.php/music-research/euterprise-ep/euterprise-record-cutting-and-artwork/

The artwork

The artwork was made by me by hand, using a combination of stencil and hand printing technology. The image is of Euterpe (muse of music), adapted from this

image:
https://commons.wikimedia.org/wiki/File:Lyon_Mosa%C3%AFque_de_la_muse_Euterpe_de_la_salle_Rameau.jpg

The creation of the artwork is documented in detail at:
http://euterprise.com/index.php/music-research/euterprise-ep/euterprise-record-cutting-and-artwork/